Performance of Persons with stuttering on self select reaction time paradigm using speech and non speech tasks

Mahesh (B.V.M)
Register No.: 08SLP015

A Dissertation Submitted in Part Fulfillment for the
Degree of Master of Science (Speech-Language Pathology),
University of Mysore, Mysore

All India Institute of Speech and Hearing
Manasagangothri, Mysore-570 006
May 2010

To my Dad, Mom

And

Lord Narayana

Certificate

This is to certify that the dissertation entitled **"Performance of Persons with Stuttering on self select reaction time paradigm using speech and non speech tasks"** is a bonafide work in part fulfillment for the degree of Master of Science (Speech- Language Pathology) of the student (Registration No. 08SLP015). This has been carried out under the guidance of a faculty of this Institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore
May, 2010

Dr. Vijayalakshmi Basavaraj
Director
All India Institute of Speech and Hearing
Manasagangothri
Mysore- 570 006

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Prof. R. Manjula

All India Institute of Speech and Hearing

Manasagangothri

Mysore- 570 006

Mysore

May, 2010

Declaration

This dissertation entitled **"Performance of Persons with Stuttering on self select reaction time paradigm using speech and non speech tasks"** is the result of my own study under the guidance of Prof. R. Manjula, Professor in Speech Pathology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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INTRODUCTION

Wendell Johnson (1930) in his autobiography described himself and said "I am a stutterer. I am not like other people. I must think differently, act differently, and live differently because I stutter. Like other stutterers, like other exiles, I have known all my life a great sorrow and a great hope together, and they have made me the kind of a person I am. An awkward tongue has molded my life". Stuttering has been viewed as a riddle due to its complexity as a speech disorder and as viewed by various investigators. The complex multidimensional nature of stuttering has received more attention than any other speech disorder. It was rightly said by Nuttall (1937) in his "Memoir of a Stammerer" that "If anyone can solve the problem of stuttering, he can solve all the important troubles of human race". The pieces of stuttering puzzle is lies scattered on the tables of speech pathology, psychiatry, neurophysiology, genetics and various other disciplines. Many researchers have taken pains in assembling some parts of this puzzle while ignoring some of the meaningful pieces seen on their own or others tables.

Many investigators have attempted to define stuttering, but the variability seen in persons with stuttering (PWS) makes it clear that this complex and variable disorder is hard to delimit. Some of the earlier definitions reflected the viewpoint of the investigators with respect to the cause or nature of the disorder. While some of the definitions were too broad like "Stuttering is a disorder of rhythm" where they failed to provide proper framework within which the disorder can be understood, other definitions addressed various behavioural features seen in individuals with stuttering. Such descriptive definitions always suffered a drawback since not all persons with stuttering show many of the observed features. Finally, there were definitions, which identified salient features, which could be used to differentiate stuttering behaviour from other phenomena with which it is usually confused. Wingate gave the most comprehensive definition of stuttering, which states that stuttering is a:

I) (a) "Disruption in the fluency of verbal expression, which is (b), characterized by involuntary, audible or silent repetitions or prolongation in the utterance of short speech elements, namely: sounds, syllables and words of one syllable. These disruptions (c) usually occur frequently or are marked in character and (d) are not readily controllable.

II) Sometimes the disruptions are (e) accompanied by accessory activities involving the speech apparatus, related to unrelated body structures, or stereotyped speech utterances. These activities give the appearance of being speech related struggle.

III) Also, there are infrequently (f) indications or report of the presence of an emotional state, ranging from a general condition of "excitement" or "tension" to more specific emotions of negative natures such as fear, embarrassment, irritation, or the like. (g) The immediate source of stuttering is some in coordination expressed in the peripheral speech mechanism; the ultimate cause is presently unknown and may be complex or compound.

No single theory has explained all the features of stuttering and each theory successfully addresses only a part of the whole phenomena. Stuttering was described in terms of psychological and learning principles during the mid 1970s. However, this notion of explaining the disorder gradually lost its importance when some of the investigators showed that speech anxiety and emotional factors were documented to be similar between persons with stuttering and those who do not stutter (Peter & Hulstijn, 1984). These findings led various investigators to view the disorder of stuttering from a speech motor control perspective and currently the disorder of stuttering is described from a motoric perspective (Adams, 1974; Kent, 1984). However, the portrayal of stuttering in the motoric facet has waxed and waned over the past few decades. Travis (1934) postulated that an inadequate cerebral dominance produces a breakdown in the motor control of speech. In 1960's and 70's, theory and research in stuttering was focused on emotional and learning theories (Shames & Sherrick, 1963; Brutten & Shoemaker, 1967; Sheehan, 1975) and by the late 1970's laryngeal and respiratory dynamics in stuttering gained importance and paved way for the understanding of stuttering in the speech motor control perspective (Starkweather, 1982; Zimmerman, 1980, 1980c; Perkins, Rudas, Johnson & Jody Bell).

The speech motor control perspective of stuttering is more than just one single theory or model and all these theories share the common hypothesis that PWS have difficulties in initiating and controlling speech movements in one way or other. They suggest that, in stuttering the speech mechanisms responsible for a precise adjustment of the respiratory, laryngeal and articulatory movements are operating less efficiently. At certain moments, this inefficiency causes a breakdown of speech fluency and results in dysfluencies. How exactly this takes place has not been understood in a strict sense. Few of the studies supported the discoordination hypothesis where they used EMG measurements (Peters, Hulstijn & Starkweather 1989). These Studies reported a disruption of normal reciprocal action of abductor muscles in non fluent utterances which inturn suggested that stuttering might be due to the discoordinated activity between and within speech subsystems. Many other studies also supported the above hypothesis (Adams, 1974; Wingate 1976; Zimmerman, 1980; Van riper, 1982; Borden, 1983; Zimmerman, 1984; Gracco, Caruso & Abbs, 1988; Harbison, Portr & Tobey, 1989; Starkweather, 1989).

Reaction Time Paradigm is the most commonly used technique to investigate motor programming in speech production and many investigators have used RT paradigms to address the issue of speech motor control (Kahneman, 1973; Sheriden, 1981; Peters, Hulstijn & Starkweather, 1989; Van Leishout, Hulstijn & Peters, 1996; Aravind & Savithri, 1997). The underlying assumption of this paradigm is that differences in the latency of reaction time (dependent variable) consequent to manipulation of the elicited stimuli (the independent variable) are a result of alteration in motor programming and helps in studying the response preparation in the temporal domain.

A two-stage model of motor programming for both speech and non-speech movements was developed by Klapp (1995, 2003). Unlike the other models, this model distinguishes two separate processes in speech motor programming namely INT/SEQ and assumes that preparation of a sequential movement involves an organization of a series of motor programs. The first process (INT) refers to the internal spatiotemporal structure of an individual unit of movement and reads it into a motor buffer (a short term memory store; Klapp, 2003). INT can be completed prior to initiation (preprogrammed) and is sensitive to unit complexity, with longer processing time for units that are more complex. The second process (SEQ) refers to the sequencing of units into their correct serial order after initiation. The SEQ process involves on-line retrieval of units from the motor buffer and therefore cannot be preprogrammed. SEQ is sensitive to the number of units in the buffer but not to the complexity of a unit.

Klapp (1995, 2003) validated the INT/SEQ model using reaction time (RT) paradigms. In a simple RT paradigm, the response to be produced on a given trial is cued before the imperative signal that prompts response production; this allows pre-programming and reflects SEQ process. In a choice RT paradigm, the imperative signal specifies the response to be produced, and thus preprogramming is not possible thereby reflecting the INT process. Klapp (1995) found an effect of button press duration (finger movements) on Choice Reaction Rime and an effect of sequence length on Simple Reaction Time.

Klapp's model (1995,2003) was replicated using a Self-Selection Reaction Time Paradigm which measured the INT and SEQ processes on each trial (Immink & Wright, 2001; Wright, Black, Immink, Brueckner, & Magnuson, 2004). In these studies the participants prepare the upcoming responses and indicated the same by pressing a button when they are ready. This preparation duration was referred to as the Study Time (ST) which inturn reflected on the INT process. A go-signal will prompt the individuals to execute the response. The latency between the go-signal and the response is measured and this was called as Reaction Time (RT) which inturn reflected on the SEQ process.

Klapp's model (Klapp, 1995, 2003) is tested on individuals with Apraxia of Speech to understand their precise nature of speech motor programming deficits

(Immink & Wright, 2001; Wright et. al., 2004). This model can be potentially used on individuals with Stuttering who also present speech motor programming deficits and hence a better understanding of the disorder can be attempted.

Need for the study

Many of the studies in the past have reported a programming deficit in Stuttering (Peters, Hulstijn & Starkweather, 1989; Aravind & Savithri, 1997; Vijay & Savithri, 2001). All the studies viewed speech motor programming errors seen in stutterers as a unitary stage and a very few of these attempted to address the nature of speech and non speech motor programming deficit in stutterers. Studies based on Klapp's model (1995, 2003) (Immink & Wright, 2001; Wright et. al., 2004) have led to the observation that speech motor programming involves two distinct processes in a hierarchical sequence and it is not necessarily a unitary process. The two processes, INT and SEQ have been studied in subjects with Apraxia of speech (Immink & Wright, 2001; Wright et. al., 2004) using Self Select Reaction Time Paradigm. Such an attempt is not made in persons with Stuttering. This study is proposed to examine the performance of Persons with Stuttering on the Self Select Reaction Time paradigm for speech and non speech tasks.

Aim of the study

The aim of the study is to compare the performance of persons with Stuttering and Normal controls on speech and non speech tasks using self select reaction time paradigm. The study investigates the difference if any between normal controls, PWS with treatment and PWS without treatment with respect to:

a) Motor programming for non speech and speech tasks, and thus its relation to INT or SEQ processes of programming.

b) The modality independent or modality dependent factors with respect to INT or SEQ processes.

c) The effect of treatment in PWS with respect to INT or SEQ processes.

Implications

- The present study helps us to understand the nature of programming errors if any seen in Persons with Stuttering and delineate the same to INT and SEQ process
- It will pave way for further investigative studies to understand the sub processes of programming deficits in stutterers if any.

Limitations of the study

- Replication of the study is required including more number of subjects in the experimental groups.
- Since the duration and intensity of therapy as variables were not controlled in experimental group 2 i.e. PWS who have undergone therapy for dysfluency, in the replication studies this factor should be controlled for its influence on RT paradigms.
- There was an artificial association created with the stimulus and the responses in the speech task, and this could be made more associative between the task and responses in future paradigms designed for an experimental task as used in the study.

REVIEW OF LITERATURE

Van Riper (1982) defined stuttering as a disruption of the simultaneous and successive programming of muscular movements required to produce a speech sound or its link to the next sound in a word. This definition suggests a possible scope of understanding the disorder from the speech motor control perspective. Over the last two decades, there has been a growing research interest in the perspective of speech motor control in stuttering. Earlier to this, investigation with respect to perceptual features of stuttering such as repetitions, prolongations and other core features did not aid in the identification and understanding of the underlying neuromotor processes of these behaviors.

The contemporary research views stuttering as a disorder of complex neuromotor control system that subserves speech production (Zimmerman, 1980a). Many of the theories share similar hypothesis that persons with stuttering have greater difficulty than those without stuttering in initiating and controlling speech movements. Some of those hypothesis include:

Stuttering and discoordination hypothesis

The "discoordination hypothesis" states that stuttering is presumably the result of constitutional inability to temporally co-ordinate respiratory, phonatory and articulatory actions in speaking (Perkins, Rudas, Johnson & Bell, 1976; Caruso 1991). The speech subsystem error has been hypothesized to be one of the potential causes in the research arena of stuttering. The subsystems like respiration, phonation and articulatory were held responsible for the disfluent behavior noted in Persons with

Stuttering (PWS). The documented reports on the subsystem errors in PWS paved way for further studies related to motor control of speech in stuttering.

A properly controlled and co-ordinated airflow is required for the fluent flow of speech. Disordered breathing was listed as one of the crucial factors causing stuttering. Few earlier findings have documented fixations of respiratory muscles during the moments of stuttering (Murray, 1932). In the later studies it was shown that there was a loss of control over the subglottal air pressure during stuttered speech (Zocchi, Estenne, Johnston, Ferro, Ward & Macklem 1990). Also, there were evidences to show that muscle groups which work reciprocally to ensure normal breathing have instead been found operating antagonistically (Murray, 1932). Series of abnormalities have also been noted in the pattern of breathing curves which include irregular respiratory cycles, prolonged inspiration/expiration, and interruption of expiration by inspiration and attempts to speak on inspiration (Zocchi et. al., 1990). Other studies have also documented higher intra oral pressure during fluent speech (Adams, 1974); higher intraoral pressure during stuttered speech (Hutchinson & Navarre, 1977); abnormal subglottal air pressure prior to a fluent speech episode and so on. These breathing abnormalities have been attributed to the competing inputs from the Metabolic Respiratory Controller (MRC) and Peri-aqueductal Grey Matter controller (PGMC) where MRC controls vegetative breathing and PGMC provides the variability required for speech production (Denny & Smith, 1997).

Laryngeal structures were viewed as the potential causal factor for the disfluent speech in the early 1970s. Many of the studies reported abnormal activity in the larynx during stuttered speech. Chevrie and Muller (1963) reported many breaks in the rhythm of the vocal fold vibration during stuttering moments using glottography. Abnormally increased action potential was seen in the disfluent speech when recorded through EMG (Bar, Singer & Feldman, 1969). Few of the objective data revealed a simultaneous contraction of adductor and abductor muscles before and during stuttering in few of the intrinsic laryngeal muscles (Freeman and Ushijima 1975, 1978; Shapiro, 1980; Metz, Conture & Colton, 1976).

Acoustic studies dominated the late 1970s and early 1980s and these data also pointed towards larynx as the most probable source for the observed disfluent behavior. Many of the acoustic studies measured Jitter, Shimmer, Voice onset time (VOT), Voice Initiation Time (VIT), Voice Termination Time (VTT), Vowel duration and Voice quality. Among these, some of the studies reported increased VOT in PWS compared to Non stutterers (Hillman & Gilbert, 1977; Metz, Conture & Caruso, 1979; Zimmerman, 1980), but few other studies did not show any significant difference between PWS and Non Stutterers in the VOT task. A number of studies have found PWS to exhibit slower VIT responses than those who do not stutter (Adams & Hayden, 1976). The focus on laryngeal structures as a factor in stuttering was further strengthened when Schwartz (1974) proposed his model on stuttering "The core of the stuttering block". He attributed dysfluent speech behavior to incoordinated activity of posterior cricoarytenoid muscle.

Due to a lack of agreement between reported studies on the role of larynx, the ideology of larynx as the causal factor in stuttering lost its significance. At the same time, few of the researchers viewed stuttering as an articulatory disorder and various studies also supported the claim. Both temporal and spatial errors were documented by few of the studies. Spatial errors included spatially restricted movements, inappropriate articulatory movements, low velocities of articulators and difficulty in stabilizing the articulatory movements (Zimmerman, 1980; Klich & May, 1982; Van Riper, 1982; Healy, 1976; Jansen, Weineke & Vaane, 1983). Spectrographic analysis revealed temporal errors like longer/shorter duration of vowels/consonants, longer duration between articulatory events and inaccurate timing (Dissimoni, 1974; Prosek & Runyan, 1982; Riemann, 1976; Cooper & Allen, 1977). Spatial errors revealed spatially restricted movements, static positioning of the articulators, low velocities of articulators and difficulty in stabilizing the articulatory movements (Zimmerman, 1980; Zimmerman & Pindzola, 1980, 1987; Jansen et. al., 1983). These studies also revealed that the length and complexity of speech tasks used to obtain acoustic measures of fluency play an important role and could account for the difference between the two groups.

Few investigators were of the opinion that it is disocoordination between the subsystems rather than any localized errors in each subsystem in PWS. Few studies through their outcome indicated that stuttering was reduced in whispered speech and practically eliminated in the silent articulation without phonation compared to voiced conditions (Wijnen & Boers, 1994). The discoordination theory which highlights discoordination between the phonatory, articulatory and respiratory subsystems was supported by Perkins, Rudas, Johnson & Bell, (1976). Since prolongation therapy provides a firm base for the coordination of different subsystems, this is also cited to be supportive of discoordination between speech subsystems leading to stuttering (Perkins et. al., 1976)

The "discoordination hypothesis" was however questioned by Wijnen and Boers (1994) and they contended that if discoordination hypothesis has to be considered as a possible etiological factor in stuttering then these irregularities should be evident prior to the stuttering moments (Wijnen and Boers, 1994). On similar lines of thinking, Conture, Colton and Gleason (1988) found that selected temporal characteristics in the perceptually fluent speech of children with stuttering aged between 2 to 8 years of age did not differ significantly form those of their normal fluent peers suggesting that there was no discoordination observed in speech related muscle contractions. Further Conture et. al., (1988) observed that generally voice onset time, voice initiation times, voice termination time and other measures which index temporal co-ordination of respiration, phonation and articulation in children with stuttering did not differ from those of the non stuttering peers, suggesting that signs of motor discoordination are events which occur consequent to stuttering rather than as antecedent event of stuttering.

A second major drawback of discoordination hypothesis lies in its inability to relate behavioral manifestations of stuttering to its motor dysfunction. Also, how exactly the discoordination can explain the core features of stuttering is not yet understood.

Speech Motor Programming in Persons with Stuttering

An alternative to the "discoordination hypothesis" is the "Speech planning hypothesis" (Postma & Kolk, 1993, 1997) where a central dysfunction is proposed which operates before the actual execution of speech occurs. The concept of a "motor program" or "plan" must be delineated before we understand "speech planning hypothesis". The speech motor plan is an elaborate representation of all or most of the 'intended utterance' constructed prior to the actual execution of the utterance itself (Sternberg, Monsell, Knoll and Wright, 1978). Such an advance preparation of the utterance is called motor pre-programming of speech. Typically it is assumed that the input to the system of speech motor planning is a phonologic representation of language, especially a sequence of abstract units such as phonemes. The output include a series of articulatory movements that convey the intended linguistic message through an acoustic signal that can be interpreted by a listener.

Most of research literature in stuttering points to PWS having more difficulty in longer words than shorter ones, more stuttering on the first word of a sentence, than on the second and third word (Brown, 1938, 1945; Sodenberg, 1966; Tornick and Bloodstein, 1976; Jayaram 1984). Few studies in India wherein in oral reading and conversation samples of PWS (Geetha, 1979) were analyzed supports that PWS have some kind of programming errors before they initiate their speech and this could be a major causal claim for stuttering (Hulstijn, 1987). In the years that followed, various groups of researchers theorized, studied and empirically established impaired programming processes for speech in stutterers (Ingham, 1998; Peters, Hulstijn & Van Lieshout, 2000). Wijnen and Boers (1994) based on a longitudinal study of two year old boys suggested that developmental stuttering in contrast to normal dysfluency in young children is significantly related to phonological encoding comprising of creation of a specified articulatory program. This requires selection of segments for a string of words; sequencing these segments within syllable frames; and fixing intonational and temporal parameter of syllables. It was also found that stuttering and disordered phonology have a complex interaction between critical/hyper vigilant self monitoring, a slow to activate phonetic plan, immature phonological encoding and/or motor execution systems (Postma & Kolk, 1993, 1997). Some of the studies related to the phonological priming also support the claim of phonological encoding errors in PWS. It has been shown that PWS have shorter reaction times when a prime related to the target word was provided than in no prime and unrelated prime condition (Conture, Melnick and Ohde, 2003).

On comparable lines Postma, Kolk (1993) proposed "Covert Repair hypothesis" which contends that stuttering is a disorder of phonological encoding rather than motoric in nature. Speech is monitored not only through an auditory component but also through an internal self inspection system which monitors the phonetic/speech program before it is executed motorically. Errors in speech programming would be detected before they are actually articulated and the covert prearticulatory repair of the erroneous speech program would result in stuttering like characteristic such as repetition and prolongations. The Covert repair hypothesis states that "PWS do not have impaired self monitoring or impaired error detection abilities or that the errors they make are different in kind from the phonetic planning errors that normal speakers make. Rather PWS make more errors than persons who do not stutter and consequently PWS have more need to make corrections. According to this hypothesis sound syllable repetitions of stuttering are seen as attempts to repair or reduce the errors. The repetitions occur as a response to the detection of an error where in the sound or syllable is restarted, and by doing so it would reduce the chances of making further phonological encoding errors. Kolk and Postma (1997) stated that "we see stuttering as a normal repair action to an abnormal phonetic plan".

They also proposed that the covert repairs made by PWS are phonologic in nature rather than motoric.

The notion that stuttering is a phonological encoding disorder can be understood better when the actual process of speech production is delineated. The model proposed by Levelt (1989) explains the nature of speech production and it also emphasizes the role of internal and external feedback loops which helps in monitoring the speech.

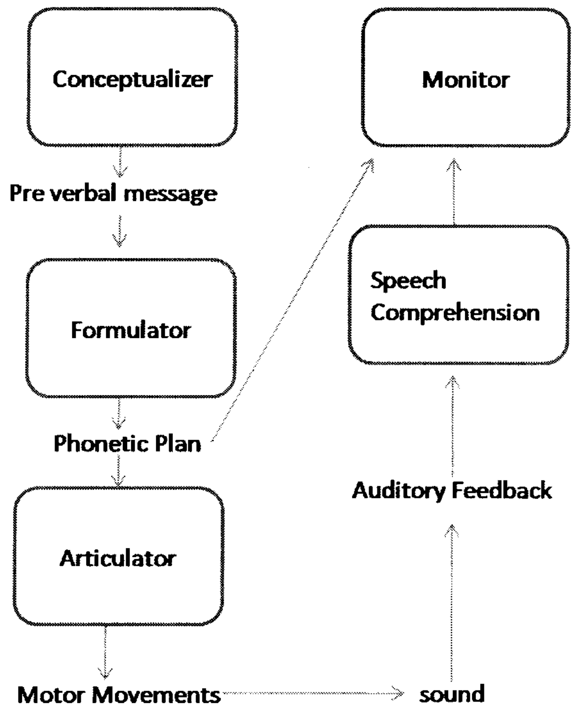


Figure 1: Levelt's Model of speech production (1989)

Two components are proposed in this theory by Levelt (1989): a conceptual component and a linguistic component. The linguistic component consists of two subsystems, one for production and one for understanding. The production system is further subdivided into a formulator and an articulator. The formulator receives a preverbal input from its preceding stage the 'Conceptualizer". The Conceptualizer is a non-linguistic stage in which the basic theme to be expressed in an utterance are selected and represented in a preverbal, propositional code based on which the 'formulator" provides the utterance with its linguistic form.

The formulator has two major active subcomponents that are currently of interest to us (1) Grammatical encoding, that is selecting appropriate words (lemmas) and ordering them syntactically; and (2) Phonological encoding, that is elaborating the sound structure of words. The end product of the formulator is a phonetic or articulatory program specifying how the utterance should be pronounced (phonemes, syllables, stress etc,). There is also a third component, "Articulator stage" where the phonetic program is translated by the motor system into audible speech movements. During understanding, a spoken utterance is mapped by the auditory component to a phonetic string from which the speech comprehension system computes parsed speech, a representation of the input speech in terms of phonological, morphological, syntactic, and semantic composition. This representation is further processed by the conceptual component. The model introduced by Levelt (1989) is basically discussed from the production view. He therefore abstracts away from details concerning the inner working of the comprehension model.

It is at the stage of "formulator" the goal directed phonetic plan is derived and the phonetic plan is monitored by an internal loop. In addition to this, after the articulation of audible speech, the auditory feedback also helps in monitoring the intended speech gesture. The claim that stuttering is a phonological encoding disorder by the Covert repair hypothesis (CRH) could be localized at the formulator stage of Levelt's model (1989).

The CRH hypothesis also explains the most plausible means by which speech errors might increase.

a) Increase speaking rate with normal rate of activation of phonological codes

Here the speakers' rate of activation of speech/target units is normal, but by increasing the rate of speaking, the speaker speeds up or moves the point of selection forward in time, thus increasing the chance that speaker will make a misselection because both target and competing units have equal levels of activation at the point of selection.

b) Normal rate of speaking with slower rate of activation of phonological codes

Here, the speaker uses a normal rate of speech but exhibits a slow or low rate of activation of target and competing units. By doing so, he or she is again likely to make a misselection because both target and competing speech units are equally activated at the point of selection. Postma and Kolk (1997) suggest that a combination of both factors i.e. increased speaking rate and slow rate of activation may contribute to disfluent behaviors.

There were few supporting studies for the view. Wijnen and Boers (1994) pointed to the fact that stutterers are slower than nonstutterers in silent reading task, which implies that the problem is not restricted just to motor execution but probably involves phonological encoding difficulty also. Postma and Kolk (1997) reported slower phonological encoding in PWS and found that PWS were able to name the second word of a word pair when the initial consonant and the vowel combination (CV condition) of the second word was same as the first word compared to the naming of a word pair where only the initial consonants were same (C condition). But, normal controls did well in the C condition and even better in the CV condition. These findings suggest that PWS have slower phonological encoding than normals.

Since CRH hypothesis could not explain developmental course of stuttering and the natural variability seen in PWS the hypothesis gradually lost its importance. Other evidences were also put forth at the same time which explained that the disordered phonology may not be the underlying factor for observed features of stuttering and two types of stuttering is seen wherein first type is characterized by disordered phonology and the second type without any phonological difficulty (Wolk, Edwards & Conture, 1993).

Models of speech motor programming

Many models have also been proposed to understand the motor planning/programming errors seen in PWS. When the research on speech motor control is closely observed, one can delineate three broad categories of models under which many known models could be fitted upon. They are:

a) Closed loop model
b) Open loop model
c) Combined model (A combination of both open and closed loop models)

Closed loop models rely on sensory feedback that results from speech production. There are three basic components in such models which include a) Effector unit b) Feedback loop c) Comparator. Here the effector unit produces the speech, which will be fedback to the Comparator to compare the target and the actual output signal through auditory or other feedback loops. The open loop model believes in pre-programming of the speech movements. It also contends that feedback is not a necessary event to execute the normal speech. This consists of an effector unit which executes a predetermined neural code and depends on the central neural input rather than on the sensory feedback. Since, the effector unit in the open loop model are pre wired to receive only one type of input signal to produce a particular motor program, it cannot correct an erroneous input signal by itself. The combined models contend that there is a central input as well as monitoring feedback loops to monitor the correctness of this input.

A comprehensive model that integrates and details the various stages and different processes involved in the speech production is required in order to understand the significance of speech motor control in speech production of PWS versus persons without stuttering. One such model is Levelt's Speech production model (Levelt, 1989) which was mentioned earlier in this review. Few other models which explains stuttering as a speech motor control disorder is described below.

Fairbank's Model (1954)

Fairbanks (1954) proposed a model of automatic control system to explain the features of stuttering. This model has three different units

Effector unit: This comprises of the vocal organs and their motor innervations and various speech subsystems like respiratory, phonatory and articulatory mechanism.

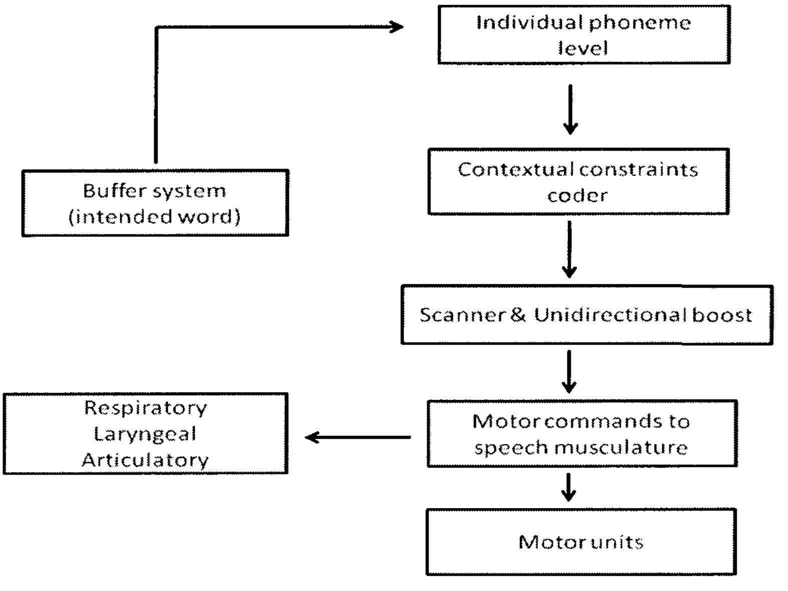
Sensor Unit: The operation of the effector unit would be fed back to the controller unit through the different sensory systems like auditory, tactile and proprioceptive feedbacks.

Controller Unit: This is a hypothetical unit which stores the ongoing speech and continuously compares this with the actual output. The error signals are generated by another unit called mixer, which contributes to the effective driving of the signal.

Fairbanks model (1954) supports the claim that in PWS there would a deficit at some place in the monitoring loops due to which unnecessary repair actions are carried out by PWS which interrupts the ongoing speech and produces stuttering like features. It also states that PWS have deficient auditory feedback loops and hence PWS rely more on the defective auditory loop than on the prominent proprioceptive and tactile feedback. The support for this notion comes from the delayed auditory feedback (DAF) studies which document a reduced overall dysfluency rate by minimizing the faulty auditory feedback and amplifying the tactile and proprioceptive feedbacks.

Mackay's Model (1970)

Mackay (1970) proposed a model of normal speech production at the phonetic level, and tried to explain abnormal speech as disruption in these processes. This model includes a buffer system which produces individual phonetic units in an abstract form but in an incorrect serial order. This abstract order of phonemes are selected individually according to the contextual constraints and further boosted. The boosted phoneme is given as a motor command to the speech musculature of different subsystems.



Mackay (1970) attributed the repetition of speech to production of two similar programs which are mutually inhibitory in nature. The inhibition of one of the similar program leads to a hyper excitation of the other, which reaches the motor unit threshold twice, inturn resulting in stuttering. Mackay (1970) explained the phenomena of prolongation and reasoned out that when a particular program gets triggered for a longer duration it results in prolongation.

Schema Theory (1988)

This is a combined model which includes both open and closed loop features. According to this model a motor program is an abstract memory that, when activated causes movement to occur. This theory postulates that there are 3 important components of motor control systems

a) *Generalized motor program component:* In this component, various force physiology parameters like velocity, speed, range, displacement and other variables are determined prior to execution.

b) *Recall schema component:* In this component a motor program based on the past experience would be developed. The motor program formulated in terms of different physiological parameters, relative positions of structures and knowledge of results regarding a particular motor action. The experience plays an important role in developing this recall schema.

c) *Recognition Component:* Recognition schema comprises initial conditions, past and current outcomes of movements, and the sensory consequences of action. As additional variability is added on with a given task, the scope of the recognition schema is expanded.

This theory views stuttering as a motor planning deficit. An erroneous abstract motor program at the level of generalized motor program would make a PWS execute the speech movements with great difficulty and results in faulty sound production. Faulty development of recall leads to incorrect selection of motor program which inturn leads to sound substitution, addition or distortion. Deficit at the recognition schema leads to an interference in the ongoing monitoring of speech and a PWS exhibits more difficulty in a novel phonetic context. Hence this theory views different types of deficits seen in PWS as being localized at different levels within a motor program.

Van Der Merwe's Model (1997)

This model proposes some of the hypothetical processes that occur during different phases of transformation of the speech code together with the different neural structures that are involved during a specific phase.

The different phases are identified as

a) Linguistic symbolic planning
b) Speech Motor planning
c) Speech Motor programming and
d) Speech Execution

Linguistic symbolic planning includes planning of semantic, syntactic, lexical, morphological and phonological planning. In speech motor planning, a gradual transformation of symbolic units (phonemes) to a code that can be handled by a motor system takes place. Here a core motor plan which consists of a spatial (place and manner of articulation) and temporal specifications for each sound is coded. This motor plan is converted into a motor program where specific movement parameters are computed which includes specifying the muscle tone, movement direction, force range, rate and mechanical stiffness of the joints. In the same phase, the selection and sequencing of different articulators for execution or a spatiotemporal plan is evolved. This plan is finally executed with a collective contribution from various motor units at the lower level. Although this model does not give a detailed explanation regarding the nature of stuttering, it views stuttering as a speech motor programming disorder. The model also attributes the core features of stuttering like repetition and prolongations to a speech motor programming deficit. It speculates the involvement of limbic and basal ganglia structures at the central level as the contributing factors for primary symptoms of stuttering.

Sternberg Model for speech motor control (1978)

This model was proposed by Sternberg, Monsell, Knoll and Wright (1978) which has four stages.

Stage I: Programming stage

An articulatory/motor plan is assembled by phonological encoding. Each articulatory plan consists of sub units or sub programs in terms of words or stress groups. The total articulatory plan is stored temporarily in an articulatory buffer awaiting further processing.

Stage II: Retrieval stage

The speech motor plan is retrieved from the articulatory buffer, unit (sub program) by unit. The retrieval takes more time if there are more units in the speech motor plan.

Stage III: Unpacking stage

Unpacking is done for each unit or sub program, for its constituents, which are motor commands for different phonological elements such as syllables within a unit. The unpacking takes more time if the unit is more complex, as defined by its size.

Stage IV: The command stage

Each individual motor command is sent to the neuro-motor system and subsequently executed. The total time needed to prepare a response is an additive composition of each time interval resulting from separate stages, since different stages are considered to be independent from each other.

1) In the light of Sternberg et. al., model (1978) , any increase in word length would have a direct effect on any of the four stages, that are proposed in the model.

   a) In the first stage, the phonological encoding presumably comprises of a specified articulatory program. Phonological encoding entails these sub processes: i) Selection of segments for a word or words. ii) Sequencing these segments to syllable frames and iii) Fixation of intonational and temporal parameters for each syllables (Levelt, 1989). Each of this sub processes consumes greater time for a larger articulatory program that is required to be constructed for a larger word. Inductive reasoning leads one to presume that, the number of nodes required to be organized in the phonological system are greater for longer utterance (Mackay, 1982)

   b) Along similar lines, the retrieval and unpacking stages are also adversely influenced by increasing response complexity.

2) It is important to note that this model is limited, since it does not add much to the understanding of specific speech motor production factors at the level of speech motor execution".

This model explains the potential effect of length of a word on dysfluency seen in PWS. It is been described from several studies that as length of an utterance increases there are more chances that the word might be stuttered (Jayaram, 1984; Weiss & Zebrowski, 1992). This effect could be localized to the retrieval stage of Sternberg et. al., model (1978) in which its been stated that longer time is needed to accurately produce a speech motor plan when the length of an utterance is longer.

Van Leishout Model (1995)

The model proposed by Van Leishout (1995) consists of three main stages:

1. The motor plan assembly stage, in which an abstract motor plan is assembled.
2. The muscle command preparation stage, in which muscle commands are turned to the context of the verbal motor task.
3. The muscle command execution stage, in which muscle commands are initiated and executed.

Motor Plan assembly stage:

This stage comprises of two sub stages namely a) phonological encoding stage and b) motor planning or encoding:

In the phonological encoding stage, the correct phonemes for a particular word or sentence are selected in such a way that segmental and metrical word information from the mental lexicon is integrated. A theory on stuttering proposed by Postma and Kolk (1993) called "Covert Repair hypothesis" attributes the speech problem of stutterers to this level of motor planning.

In the motor planning stage, the phonological syllabic units are transformed into abstract motor plans. The planning occurring at this stage is said to be abstract since it does not convey specific information about the actions of the individual articulators but rather it relates to a group of actions for executing a goal. Ultimately, the motor plan assembly stage produces a motor plan of the intended utterances which would then be loaded to the short term memory buffer.

Muscle command preparation stage:

In the unpacking stage of motor plan, all the processes that translate the motor plan generated in the motor plan assembly stage into context-specific muscle activation patterns of commands that are needed to activate the individual articulators are involved. It is also noted that a stored motor plan does not specify the muscle commands directly. The commands have to be adjusted with respect to various situational constraints and this would be carried out by the parameter setting. The parameter setting sets the variables like stress, loudness and rate depending on the speaking situation.

Muscle Command Execution Stage:

After setting various parameters to the motor plan, the motor units of the muscles in speech motor effector system are activated, which gives rise to muscle contractions across various subsystems of speech like respiratory, phonatory and articulatory subsystems involved in speech production. This results in generation of the air pressure differences which inturn generates speech sounds.

Each sub stage of this model explains different aspects of fluency breakdown seen in PWS. The motor plan assembly stage posits that PWS might have phonological encoding errors which are supported by other investigators (Postma & Kolk, 1993, 1997). The muscle command preparation stage explains the deficits in the force physiological parameters evident in stuttered speech. It is been documented that PWS exhibit reduced ability in precise regulation of speech related forces. Grosjean, Galen, Jong, Van Leishout and Hulstijn (2002) have reported that PWS exhibit less strength and inaccurate timing when pressing their lips on a pressure transducer. Subsystems errors seen in PWS could be localized to the muscle command execution stage of the Van Leishout's model (1995)

Reaction time studies and motor programming

The most common experimental approach used to study the speech motor programming in PWS is the of Reaction Time (RT) paradigm. These RT paradigms helps in understanding the coordination of various speech subsystems like respiratory, phonatory and articulatory mechanisms and thereby specifies the characteristic phonetic response which has to be produced by the participants. This measures how a PWS would be able to initiate and terminate the speech or non speech gestures in response to an external stimuli. Utilizing this notion, there have been a variety of vocal reaction time studies beginning in the early 1970's (Adams, Freeman and Conture, 1984). The majority of these studies have recorded slower reaction times for stutterers than for non stutterers.

A growing body of literature suggests that there is increased reaction time or latency when longer or more complex movements have to be initiated. Although substantial evidence is available in favour of the relationship between movement complexity and reaction time, there are innumerable controversies about the optimal paradigm to study programming. Both speech and non speech tasks have been studied using the RT paradigms. In one of the studies done by Starkweather, Franklin and Smigo (1983), PWS and matched controls were made to say 'uh' or press a button in response to the offset of tones varying randomly in duration. The results revealed that PWS were significantly slower in both speech and non speech tasks, but the correlations between voice and manual reaction times were not significant. The PWS showed a significantly larger difference between vocal and manual reaction times than the persons without stuttering. Investigations comparing the simple voice reaction times (VRT) of PWS and persons without stuttering have shown consistently that adult PWS as a group are slower and more variable than controls in initiating voicing in response to auditory and visual cues (Adams & Hayden, 1976; Cross & Luper, 1979, Cross, Shadden & Luper, 1979). Similar results have been reported for children who stutter, although the relative group differences across studies have varied (Cross & Luper, 1979; Cullinan & Springer, 1980, Reich, 1981). Cullinan and Springer reported significantly longer Voice Reaction Time for children who stutter and are below the age of 12 years compared to their age matched controls.

Few studies revealed that PWS may not exhibit slower reaction time in speech or non speech related tasks. McFarlane and Prins (1978) reported that adult PWS exhibited longer neural reaction times than controls for a lip closure task, in the absence of vocalization, which indicates that they have difficulty in controlling non speech movements like a lip closure. In addition to the above study, Zimmerman (1980a, 1980b) reported that adult PWS exhibited lack of coordination in temporal and spatial relationships for the tongue, lips and jaw during fluent and disfluent utterances. The movement trajectories' obtained in the study revealed extreme variability and slower articulatory movement velocity. Acoustic studies also have reported atypical temporal articulatory patterning in the fluent speech of stutterers.

There are few contradictory studies which documented that persons with stuttering may not have non speech motor deficit as documented in the previous research findings. Till, Reich, Dickey and Seiber (1983) carried out a phonatory and manual reaction time studies on children with stuttering. The results revealed that PWS showed more variability in the phonatory tasks compared to controls but no differences were found between the two groups for non speech phonatory responses such as inspiratory phonation and expiratory throat clearing. Overall no significant differences were found between both the groups across the tasks. Till et. al., (1983) concluded that stuttering in children was not related to an organically based overall slowness affecting the temporal course of voluntary sensorimotor events during all types of simple reactive responses.

A recent research finding by Olander, Smith and Zelaznik (2010) have found that children with stuttering show more variability in a non speech task like clapping. Children with stuttering were asked to clap along with the metronome beat which produced a inter beat interval duration equivalent to 600ms. Results revealed that children who stuttered did not significantly differ from typically developing children on mean clapping rate or number of usable trials produced. However, they produced remarkably higher variability levels of inter-clap interval. They also found two subgroups of children with stuttering with varied performance in this non speech task. One subgroup of children who stuttered clustered within the normal range, but 60% of the children who stuttered exhibited timing variability that was greater than the poorest performing typically developing child. Olander et.al., (2010) concluded that there is a subgroup of young stuttering children who exhibit a non-speech motor timing deficit.

The main question which arises from the above series of studies is that whether individuals with stuttering have motor interference only in the speech related activity or whether it reflects intermittent variation in some common motor control system. It has been proposed that if atypical manual as well as speech related reaction times are observed in some PWS, and if the correlation between them are high, then the errors can be attributed to a common motor control system for the observed features.

Another major question that arises from the reaction time research has to do with the length of the speech response. Speech RT studies have often used isolated vowels, single words, and short phrases as responses. The isolated vowel studies have often found significant differences between PWS and normal controls (Adams & Hayden, 1976, Cross & Luper, 1979; 1983; Cross, Shadden, & Luper, 1979; Franklin, Smigo & Starkweather, 1984) but there have also been studies using isolated vowels in which no significant differences were found (Murphy & Baumgartner, 1981, Watson & Alfonso, 1982). Those studies which have used words or phrases have found that stutterers were slower in speech initiation than nonstutterers (Starkweather, Hirschman & Tannembaum, 1976; Till, Reich, dickey, & Seiber, 1983; Alfonso & Watson, 1982, 1983). Longer utterances are motorically more complex than shorter ones, so one explanation for this combination of results is that the additional motoric complexity of the longer responses increases the difference in RT between PWS and normal controls. Indeed, Reich et. al., (1981), Till et. al., (1983) have suggested that speech reaction time may be influenced by the motoric complexity of the response.

The literature on stuttering frequency also suggests that motoric complexity may play a role in the precipitation of stuttering behavior. The tendency of stuttering to occur more frequently on longer than shorter words and sentences (Jayaram, 1984) has been well established. It may be the additional motoric complexity of longer utterances that causes them to be stuttered more often than shorter ones. Few studies also supported the fact that increasing the task complexity can increase the susceptibility for the dysfluent behaviours in PWS. Maner, Smith and Grayson (2000) measured the lower lip movement from 8 adults who stutter and 8 normally fluent controls. A target phrase in isolation (baseline condition) and the same phrase embedded in utterances of increased length and/or increased syntactic complexity was chosen. The spatiotemporal index (STI) was calculated to infer the stability of lower lip movements across multiple repetitions of the target phrase. Results indicated that adults who stutter demonstrated higher overall STI values than normally fluent adults across all experimental conditions, indicating decreased speech motor stability. The speech motor stability of normally fluent adults was not affected by increasing syntactic complexity, but the speech motor stability of adults who stutter decreased when the stimuli were more complex. Increasing the length of the target utterance without increasing syntactic complexity did not affect the speech motor stability of either speaker group. These results indicate that language formulation processes may affect speech production processes and that the speech motor systems of adults who stutter may be especially susceptible to the linguistic demands required to produce a more complex utterance.

In one of the recent model related to motor control, Klapp (2003) revealed that motor programming has two substages a) Programming of the motor sequence occurs in advance and the time required for that preparation can influence reaction time (RT) b) A complex response is structured as a sequence of units or chunks. Programming of the motor sequence in advance is termed as INT, where the internal structure of each chunk is programmed. Whereas programming of the chunks in a particular sequence requires SEQ process. The two processes can be delineated with different patterns of Reaction Time paradigm.

The INT process can be understood with the help of a Choice reaction time paradigm. In a Choice Reaction Time paradigm, the imperative signal specifies the response to be produced and thus the pre programming is not necessary. For instance initially an 'alerting' signal would be given, followed by which a 'response cue' would be provided where the type of response required is specified. Here, the subject has to think what type of response he or she has to produce after the appearance of the response cue and then the required response should be executed. It was hypothesized that if the cue specifies a simple response then the reaction time might not be longer, but if at all a complex response has to be produced then the subject might require more time to pre program the responses. Hence, the choice reaction paradigm depends upon the complexity of the cue rather than on the number of units in the response which has to be executed.

In a simple Reaction time Paradigm, the response to be produced on a given trail is cued before the imperative signal that prompts for the response production. This allows for the pre programming of the responses and hence the SRT is sensitive to the number of units which has to be programmed. More the number of units longer would be the reaction time for the SRT.

The evidence for the same was produced by Immink, wright and Klapp (1995, 2001) by using manual key press responses. Participants were instructed to press the keys on a Morse code machine. The press duration has to be pre programmed by the participants i.e. if a cue for a short press was given then they pressed the button "dit" and if a cue for longer press was given then they were made to press the button "dah". The choice reaction time was longer before a single pressing action when the action was long than when it was when the action was short. It was also documented that when the number of chunks increased the simple reaction time became longer compared to the choice reaction time paradigm.

The findings were replicated by another group of investigators using self select reaction time paradigm (Immink & Wright, 2001; Magnuson, Wright, Robin, Black & Breuckner, 2004). They measured both the INT and SEQ within a trial which was actually measured in two different trials in the original Klapp's experiment. In the self select reaction time paradigm, the subjects were instructed to prepare the upcoming response and indicate the readiness by pressing a button after they have prepared. This preparation time was termed as Study Time (ST) which reflected the INT process. After the button press a variable delay was initiated which was followed by a go signal which prompted the subjects to execute the response.

The latency between the onset of the 'go' signal and the initiation of the response is termed as SEQ. They replicated the earlier findings that the response complexity increased the INT latency and the presence of more number of units within a response increased the SEQ process.

The same model has also been extended for understanding the motor programming which occurs during speech programming. Klapp (2003) contended that by increasing the number of syllables and making it program as a single chunk, increased the Choice reaction time but did not affect the Simple Reaction Time paradigm. Again the same modified self –Select Reaction time paradigm could be used to understand the speech motor programming in normals as wells in disordered population.

The self select reaction time paradigm was used on individuals with Apraxia of Speech (AOS) to delineate the nature of the disorder (Maas, Robin, Wright and Ballard, 2008). Both speech and non speech tasks were used where, the non speech task involved pressing of different keys of a computer key board for a pre-specified duration of time and length. The speech task involved production of a nonsense syllable /ba/ for specified length and duration. Results revealed that individuals with Apraxia of speech has longer preprogramming time (INT) but normal sequencing and initiation times (SEQ), relative to controls.

Though stuttering is viewed as a motor programming disorder by various theories and models, they viewed 'programming' as an unitary stage. Also, there were contradictory evidences for stuttering as a disorder at the planning level which utilized models inferring the motor planning as a single stage (van Lieshout, Hulstijn

& Peters, 1996). The present study is undertaken to study the programming errors which could be seen in PWS. The Self-Select Reaction time paradigm (Immink & Wright, 2001; Wright, Black, Immink, Brueckner & Magnuson, 2004) is used to delineate the nature of programming deficits which could be evident in PWS. Both speech and non speech tasks which taps the motor programming is chosen to understand whether the programming errors are localized only to a speech subsystem or is it localized to a general motoric action reflecting a modality independent motor programming impairment.

METHOD

The study was undertaken to compare the performance of persons with Stuttering and Normal controls on speech and non speech tasks using Self Select Reaction Time paradigm (Immink & Wright, 2001; Wright et. al., 2004) for speech and non speech tasks to understand the two processes, INT and SEQ processes of speech programming. The study investigates the difference if any between normal controls, PWS with treatment and PWS without treatment with respect to:

d) Motor programming for non speech and speech tasks, and thus its relation to INT or SEQ processes of programming.

e) The modality independent or modality dependent factors with respect to INT or SEQ processes.

f) The effect of treatment in PWS with respect to INT or SEQ processes.

Participants: There were two groups of participants:

a) Experimental group

b) Control group.

The experimental group was further divided into

i) Persons with stuttering without treatment

ii) Persons with stuttering with treatment.

Fifteen PWS who had undergone treatment, 10 PWS without any treatment and 25 Normal controls matched for age and educational level in the age range of 16-30 years were included.

Demographic details of the participants

Groups	Number of participants	Mean age (in years)	Gender	
			Males	Females
Normal controls	25	22.3	11	14
PWS with treatment	15	23.5	15	-
PWS without treatment	10	22.6	9	1

Inclusion criteria

- Participants were screened for any visual, auditory, psychological, neurological and gross language deficits. Auditory deficits were ruled out through an auditory screening evaluation. Psychological and Neurological deficits were ruled out through clinical examination.
- Quick Neurological Screening Test (QNST) (Mutti, Sterling, Spalding and Rafael, 1972) was administered to rule out the presence of any soft neurological signs.
- Those subjects who passed the Linguistic Profile Test (Suchitra & Karanth, 2007) standardized for adults were included to rule out any language impairment.
- All the participants had a basic qualification of 10^{th} grade in English Medium.
- The severity of stuttering in the experimental group was rated using Stuttering Severity Instrument (Riley, 1986) by an experienced Speech - Language Pathologist. Individuals with mild to moderate degree of stuttering only were included in the experimental group.

Exclusion criteria

- Those individuals with a history of seizures, open head injuries and motoric deficits were excluded.

Informed consent was obtained from the participants before conducting the study..

Instrumentation

The study was conducted in an individual set up with no distractions. The Self Select Reaction Time Paradigm was developed using DMDX (Kenneth & Jonathan, 2003) software. DMDX is a freeware which was basically developed for behavioral psychology experiments for measuring reaction times. Two separate program has to be run before doing any experiment through DMDX. The first software is called TimeDx developed by same authors, which will check the refresh rate and other parameters on the screen of the monitor which are optimal for displaying audio or video files. This refresh rate varies across different computers and models. DMDX software works only after running the TimeDx module. Before starting the experiment a separate program has to be written depending on the experimental paradigm using DOS prompt. An experiment can be run only when the whole program is ready for all the items. Before conducting the experiment the written program has to be syntactically checked based on the option that is available for the same. Subject details can also be added before running the experimental trial.

In this study, two separate programs, the first a non speech program and the other a speech program were individually programmed by the investigator under the guidance of the authors who developed DMDX. These two programs were loaded on to a Personal Computer while carrying out the experiments. The computer was connected to a compatible microphone for recording the Speech Reaction Time in the speech experiment. Before starting the experiments it was ensured that the software loaded is working properly by the experimenter. In the speech task the waveform recorded was analyzed with the help of Praat software. Praat is a free scientific software program for the analysis of speech in phonetics. It has been designed and continuously developed by Boersma and Weenink (2010) of the University of Amsterdam. The program also supports speech synthesis including articulatory synthesis. While analyzing the waveforms recorded from DMDX software, Praat was used where the sampling frequency was adjusted to 44,100 Hz which provides good auditory resolution of the recorded samples.

Task and procedures

Self Select Reaction Time Paradigm (Immink & Wright, 2001, Wright et. al., 2004) was used to measure 'Study Time (ST) and Reaction Time (RT) in both Speech and Non Speech tasks. A pilot study was conducted to test the sensitivity and applicability of the Reaction Time Paradigm. The pictorial representation of self select paradigm is as follows:

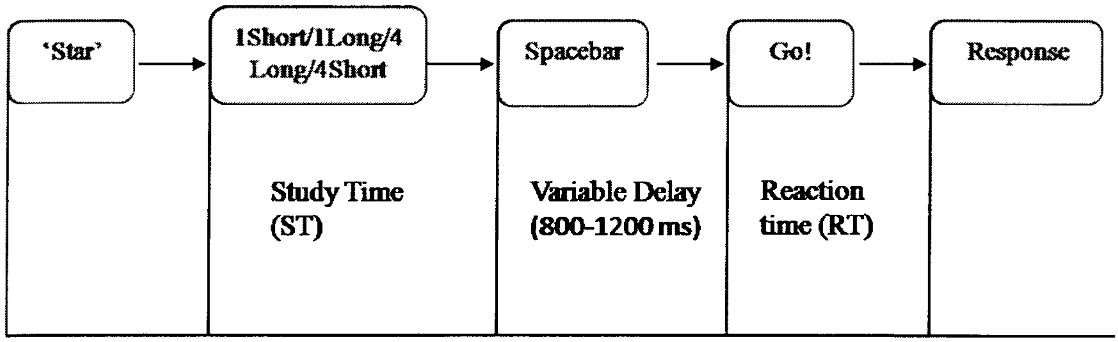


Fig.1: Self Select Reaction Time Paradigm (Immink & Wright, 2001; Wright, Black, Immink, Brueckner & Magnuson, 2004)

As is evident from figure 1, initially a visual symbol 'star' will appear on the screen and this symbol will alert the participants to pay attention to the upcoming stimuli. After the appearance of the star, a visual word is displayed which can be either 1 short / 1 long / 4 short / 4 long. At this stage, the participants get ready to execute the response that they are going to produce after they see the visual stimuli. When they are ready with respect to the key press (what key they are going to press for a particular duration) as required in the non speech task or what syllable should be produced for a particular duration as in the Speech task, they are asked to press the 'spacebar'. The time taken by the subjects to press the spacebar from the appearance of the visual cue is recorded as the Study Time (ST). ST reflects the INT process (internal spatiotemporal structure of an individual unit of movement) of motor programming of Klapp's model (1995, 2003). After this delay, a visual stimuli 'Go!' is presented and the subjects are asked to produce the responses as fast as possible. The time gap between the appearance of the go signal and the initiation of the response indicates SEQ process of motor programming proposed by Klapp (1995, 2003). SEQ sequences the programmed units of movement and stores it in a short term buffer.

Material

The experimenter synthesized two different pure tones of 1000 KHz for a duration of "150ms" and "450ms" with the help of 'Cool Edit Pro software (Syntrillium Software). No variation in terms of amplitude or frequency was created. The rationale behind using the tones of 150 and 450 ms was based on the Morse Code System where these are the durations which are used to indicate a short press 'dit' and a long press 'dah'. Some of the earliest studies have used Morse Code Button Presses and Sequences as an ecologically valid motor learning task.

A visual alerting symbol "star" and the key press priming visual symbol "Go!" were directly downloaded from the internet. These two symbols were used in both speech and non speech Self Select Reaction Time paradigm of this study.

For the speech programming task using the Self Select Reaction Time Paradigm the experimenter recorded the phoneme /pa/ using the Praat software. The recording was done in a quiet situation without any background noise. This was recorded by the experimenter at his habitual pitch and loudness without varying the intonation significantly. The vowel portion was edited to synthesize a shorter /pa/ of 150 ms duration and a longer /pa/ of 450ms. The rationale behind using a nonsense syllable was to minimize the linguistic load (word finding difficulties) and also because it was the closest analog and could be compared to the finger press task (Klapp, 1995, 2003; Mass, Robin, Wright & Ballard, 2008).

Pilot study:

A pilot study was conducted to ensure the utility of the program developed using the DMDX software for the experimental tasks. Five participants who were not part of the actual experiment, in the age range of 20-26 years were included. These participants were administered both speech and non speech programming task that were developed by the investigator.

Instructions: Non speech tasks

- Initially, subjects were familiarized with the different key press responses which included a "Short press" and a "Long Press". Each subject was provided with an auditory model regarding "short" and "long" press responses. The auditory model consisted of two separate tones which included a short duration tone of '150 ms" and a long duration tone of "500 ms". These two tones were presented several times until the subject understood the difference between the two tones. When the subjects were familiarized with the different types of responses, they were asked to press the "S" key on the keyboard of the computer for the "Short press" (for a duration equivalent to "150 ms") and "L" key of the keyboard for the "Long press" (for a duration equivalent to "450 ms"). Later they were familiarized with the number of responses which they have to produce which included either a "single key press" or a "multiple key presses". Accordingly, four different key press responses would elicit four targets namely; 1S (Single short press: 150 ms), 1L (Single long press: 450 ms), 4S (SLLS sequence: 150-450-450-150 ms), 4L (LSSL sequence: 450-150-150-450 ms).

Each experimental trial followed a particular sequence in which:

- Each trial was initiated by presenting a visual symbol of "star" which appeared on the centre of the screen for a duration of 1000 ms.
- This was followed by presenting the visual cue indicating the required response. The required response could be 1 Short, 1 Long, 4 Short or 4 Long.
- The subjects were asked to think about the required response which they have to produce mentally and press the space bar when they are ready to respond.
- This preparation interval is termed as "Study Time" and this would reflect the demands associated with the INT process.
- Pressing the space bar induces a variable delay ranging from 800 to 1200 ms.
- Following the variable delay a 'go' signal of 300 ms was presented. This prompts the individual to execute the required response.
- The time between the 'go' signal and the response is called "Reaction Time" and this would reflect on demands associated with SEQ process.
- Totally there were 10 blocks in which each block consisted of 4 different types of responses i.e. 1Short, 1Long, 4Short and 4Long.
- The order of presentation of different types of responses was randomized across 10 blocks which totally constituted 40 trials.

Instructions: Speech tasks

- Initially an auditory model of non sense syllable /pa/ which varied in duration and length was recorded by a male native speaker. The participants were familiarized with the nonsense syllable /pa/ which varied in terms of syllable duration and sequence length. This included a "Short syllable" and a "Long Syllable". A short syllable had a duration of 150 ms and the longer one was of

450 ms. Each participant was provided with an auditory model of "short" and "long" syllable responses where each syllable differed only in terms of overall vowel duration. These two syllables were presented several times until the participant understood the difference between the two syllables. When the participants were familiarized with the different types of responses, they were asked to produce a "Short /pa/" for a duration equivalent to "150 ms" and a "Long /pa/" for a duration equivalent to "450 ms".

- Later they were familiarized with the number of responses which they had to produce which included either a "single syllable" or a "multiple syllable sequence" responses. Accordingly, four different syllabic productions would elicit four targets namely; 1S (Single short syllable: 150 ms), 1L (Single long syllable: 450 ms), 4S (SLLS sequence: 150-450-450-150 ms), 4L (LSSL sequence: 450-150-150-450 ms).
- The experiment begins with the presentation of the "READY" signal which will appear on the centre of the screen for a duration of 1000 ms followed by a visual cue of 1 Short, 1 Long, 4 Short or 4 Long. The presentation of the visual cue prompted the required response from the subjects.
- The subjects were instructed to press the space bar when they were ready; this measures the Study Time (ST) and in turn reflects on the INT process.
- Pressing the Space bar produced a variable time delay followed by a 'go' signal prompted for the execution of the response.
- The time delay between 'go' signal and the response is called "Reaction Time (RT)" and reflected on the SEQ process.

- Totally there were 10 blocks in which each block consisted of 4 different types of responses i.e. 1Short, 1Long, 4Short and 4Long.
- The order of presentation of these was randomized across 10 blocks which totally constituted 40 trials. Incorrect responses like 'Too early' (responses initiated during the delay interval), 'Too short /Too long' where the overall response duration exceeded a pre specified range of acceptability (100 ms above or below target duration for the single presses, 500 ms for the sequences) were excluded from the analysis.

The participants were seated comfortably in a room with no distractions. Before carrying out the tasks, participants were provided with suitable instructions with respect to non speech and speech tasks as explained earlier. These instructions were presented as power point slides separately for non speech and speech tasks. They were instructed that initially a 'star' will appear on the screen followed by a 'visual word' which cued the required response. Then they were asked to prepare the responses and then press the spacebar as soon as possible, which measured the Study Time (ST) inturn reflecting the INT process. After a pre-specified variable delay of 800-1200 ms, they were asked to execute the key press responses when a visual cue "Go!" came on the screen. The time taken from the appearance of the 'Go!' signal to the initiation of responses measured the Reaction Time (RT), which inturn reflected the SEQ process. The same procedure was followed while carrying out the speech task but instead of key press response a verbal response consisting of a non sense syllable /pa/ was asked to produce in two different durations of 150ms and 450 ms.

Totally there were 10 blocks containing 40 trials in both speech and non speech task. Each block consisted of four trials which included 1S, 1L, 4S or 4L. Followed by the instructions a single block consisting of 4 trials was shown to the participants' in order to understand the task better.

The findings of the pilot study indicated that the participants took longer reaction time for the INT task compared to the SEQ task in both speech and non speech task. Also, it was noticed that the subjects committed more mistakes in the first block and the responses were slowed down at the last block. Hence, it was decided to exclude the first and last blocks in the experimental trials.

Experiment of the study: The RT paradigm developed by the investigator which was tested and modified based on the outcome of the pilot study were included in the experiment of this study.

The present study included two experiments:

a) Experiment 1: RT paradigm for non speech tasks
b) Experiment 2: RT paradigm for speech tasks.

Experiment 1: RT paradigm for non speech tasks

Finger movement task as used in earlier studies (Klapp, 1995; Wright et al 2004) and was tested in the pilot study was included in this experiment. Appropriate instructions were given to each participant regarding different key presses and their sequences which are used in the experiment. The instruction was prepared using Power Point slides by the experimenter and this was presented to each subject before they participated in the experimental trials.

Experiment 2: RT paradigm for speech tasks.

Speech movements used in earlier studies (Klapp, 1995; Wright et al 2004) and was tested in the pilot study was included in this experiment. Appropriate instructions were given regarding different speech movements and their sequences which were used in the experiment. The instruction was prepared using PowerPoint slides by the experimenter and this was presented to each subject before they participated in the experiment.

Analysis

Experiment 1: Initially, raw scores were obtained for each condition (1S, 1L, 4S and 4L) in Non speech tasks across Study Time (ST) and Reaction Time (RT). Later mean scores were calculated for each condition across ST and RT.

Experiment 2: Here also, raw scores were obtained for each condition (1S, 1L, 4S and 4L) in Speech tasks across Study Time (ST) and Reaction Time (RT). Later mean scores were calculated for each condition across ST and RT.

Mean scores of Study Time and Reaction Time for speech and non speech tasks of the participants were calculated and compared within the group and across the groups and also across four different conditions. While analyzing the speech motor programming the Reaction Time was measured from the burst of the syllable /pa/. The raw data was treated with suitable statistical procedures to make the inter and intra group comparisons and the same is presented and discussed in the following chapter.

RESULTS AND DISCUSSION

The study was undertaken to compare the performance of persons with Stuttering (PWS) and Normal controls on speech and non speech tasks using Self Select Reaction Time paradigm (Immink & Wright, 2001; Wright et. al., 2004) to understand the two processes, INT and SEQ processes of speech programming. The study investigates the difference if any between normal controls, PWS with treatment and PWS without treatment with respect to:

- Differences if any in the motor programming for non speech and speech tasks, as reflected on the Self select reaction time paradigm and thus its relation to INT or SEQ processes of programming.

The results are presented and discussed under the following sections:

A. Between group comparisons of Study Time [ST] & Reaction Time [RT]

B. Within group comparison across non speech and speech tasks for both ST and RT measures.

C. Within group comparison of different conditions (4S, 4L, 1S & 1L) of the experiment across non speech and speech tasks for both ST and RT measures.

D. Within condition comparison across groups.

E. Within group comparison of various conditions.

A] Between group comparisons across non speech and speech tasks

a] Non speech Task: Study time [ST] and Reaction time [RT]

Table 1: Mean (in msec) and standard deviation for study time and reaction time across subjects in non speech tasks.

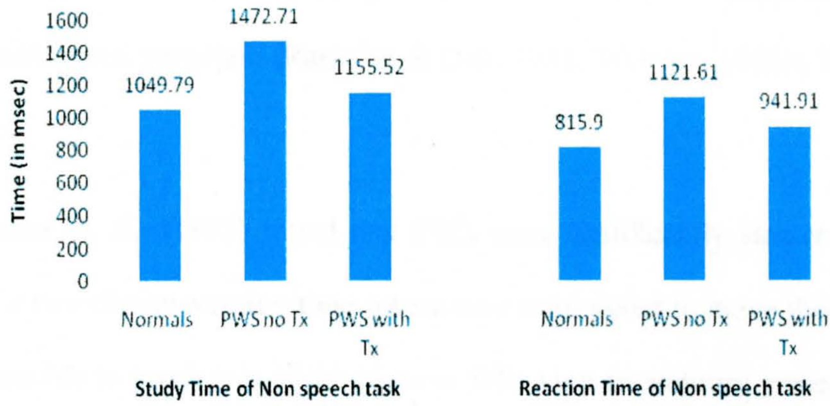
Experimental condition	Groups	N	Mean	Standard deviation	F value	sig
Study Time						
Non Speech Study time	Normals	25	1049.79	331.66	5.138	.01*
	PWS No Tx	10	1472.71	324.71		
	PWS with Tx	15	1155.52	402.23		
Reaction Time						
Non Speech Reaction Time	Normals	25	815.90	277.86	3.872	.028**
	PWS No Tx	10	1121.61	360.06		
	PWS with Tx	15	941.91	283.70		

PWS No Tx = Persons with stuttering without treatment, PWS with Tx= persons with stuttering with treatment

"*" = significant difference at 0.01 level of significance for ST

'**" = significant difference at 0.02 level of significance for RT.

Graph 1: *Mean (in msec) of ST and RT for nonspeech task between groups.*



MANOVA was used to compare the differences across subjects in non speech task. Results in Table 1 and Graph 1 point to a significant difference at less than 0.02 level between the three subject groups across non speech study time (NSST). The overall reaction time for the NSST was shortest for normal controls followed by PWS with treatment and then the PWS without treatment. That is normal controls showed shorter reaction time for programming the finger press in the non speech task compared to the other two experimental groups. Within the experimental groups, the PWS group with treatment showed shorter reaction time compared to the PWS group without treatment. But, both the experimental groups had significantly longer reaction time compared to normals.

The study time reflects the INT process [Klapp's model (1995, 2003)]. INT refers to the organization of the internal spatio temporal structure of an individual unit of movement which is fed into a motor buffer (Klapp, 2003). The longer study time in the two experimental groups indicate that PWS took longer time in organizing the spatial temporal characteristics of an individual unit of utterance. The results obtained in the present study are in congruence with other studies which have used a different experimental paradigm (Rastatter & Dell, 1985; Webster, 1986b; Webster & Ryan, 1991).

Rastatter et. al., (1985) found that PWS were significantly slower than non stutterers on a two choice reaction time where they were asked to move their hand as quickly as possible to touch two of the pictures following an auditory presentation of the word. Webster (1986b) found that PWS were not only less accurate but also showed longer reaction times in a task wherein they were asked to tap their fingers repeatedly in a sequential manner following a visual cue. Once initiated, however, the sequence was repeated as quickly by the PWS as by non stutterers. Webster and Ryan (1991) found that PWS were significantly slower than non stutterers in terms of manual choice reaction times. Webster et. al., (1991) found that PWS were significantly slower when the complexity within the choice reaction time varied i.e., the subjects were asked to decide to press a particular key depending on the visual cue and the number of visual cue varied between 1 to 4. It was found that as the number of choices increased, the reaction times also increased. This according to Webster et. al., (1991) suggested that PWS exhibit programming or planning and organizational difficulties when compared to normals. Similar results have been found in the present study where PWS showed longer absolute reaction time in the NSST task implicating the INT process of speech programming.

The results in table 1 and graph 1 also points to the fact that there is a significant difference at 0.02 level of significance between the three subject groups across non speech reaction time (NSRT). It is seen that the overall reaction time for the NSRT was shortest for normal controls followed by PWS with treatment and finally by PWS without treatment

The reaction time in the non speech task reflects the SEQ process [Klapp's model (1995, 2003)]. The SEQ sequences units into their correct serial order after initiation. The SEQ process which is reflecting the reaction time is tapped through a simple reaction time task where the subject was asked to press the predetermined buttons on the computer as soon as he/she gets a visual cue. Hence the results of the present study could be compared with other studies which have used non speech tasks in simple manual reaction time paradigms. Many studies support the view that PWS are significantly slower in simple manual reaction time paradigms (Cross & Luper, 1985; Cross & Cooke, 1979; Starkweather, Franklin & Smigo, 1981).

Cross and Luper (1983) described that PWS as a group showed significantly longer and more variability in manual reaction times compared to the normal controls. Cross et. al., (1983) measured the manual reaction times by making the subjects respond to the initiation of an auditory pure tone and the results revealed that PWS had longer and more variable manual reaction time than those who did not stutter. Many other studies have shown statistically significant differences in the non speech reaction time between PWS and Normal controls (Starkweather et. al., 1981; Cross et. al., 1979). Though many of the studies have shown statistically significant differences, few of the studies revealed contradictory results (Prosek, Montgomery, Walden & Schwartz, 1979, Reich, 1981) wherein they showed no statistically significant differences between PWS and those who do not stutter and this was attributed to smaller groups of subjects, nonuniformity in controlling the severity of the problem and subject sampling errors.

To verify the difference between the means of the groups in non speech task for the RT, Duncan's post hoc analysis was used.

Table 2: Duncan's Post hoc test for non speech study time and reaction time across subject groups

Experimental Condition	Groups	Subset	
		Means	Means
	Study Time		
Non speech Study Time	Normals	1049.79	
	PWS with Tx	1155.52	
	PWS with no Tx		1472.71
	Sig	0.42	1.00
	Reaction Time		
Non speech Reaction Time	Normals	815.90	
	PWS with Tx	941.91	941.91
	PWS with no Tx		1121.61
	Sig	0.42	1.00

Table 2 shows the Duncan's post hoc analysis and it reveals a significant difference between normals and PWS with no treatment and significant difference between PWS with treatment and without treatment. The PWS group with treatment performed similar to the normal controls, and this could be attributed to the treatment variable. But it is of real interest to understand how a speech oriented treatment affects the non speech behavior. It could be logically speculated that if the motor neuron pools for non speech and speech tasks share some common strategies (Cross & Luper, 1983) then changing one of the programming pattern could have a favorable effect on the other. In this context, it means that the influence of speech therapy in PWS could have equally influenced the speech as well as the nonspeech task. It could be hypothesized that, treatment has a favorable effect on the programming of the non speech movements although the treatment in the form of speech therapy aimed at improving speech fluency. This leads one to speculate that the motor deficits could be modality independent also proves to be an interesting fact that the underlying motor control deficits is modality independent but further controlled studies are required to explore this notion

In the Non speech reaction time task it is evident that there is a significant difference between normals and PWS without treatment. But, the PWS with treatment performed like those of normals as well PWS without treatment. Since there was no difference between normal controls and PWS with treatments, it would be interesting to know how a treatment geared towards improving the speech could have influenced the performance in the non speech task. If the lack of difference is due to the post therapy effect then it could be concluded that a common motor control strategy exists between speech and non speech task and hence any changes created on one particular task would affect the other (Cross & Luper, 1983). But, the lack of difference between the treatment and no treatment group of PWS gives rise to questions as to whether the treatment has really produced any significant differences in PWS with treatment.

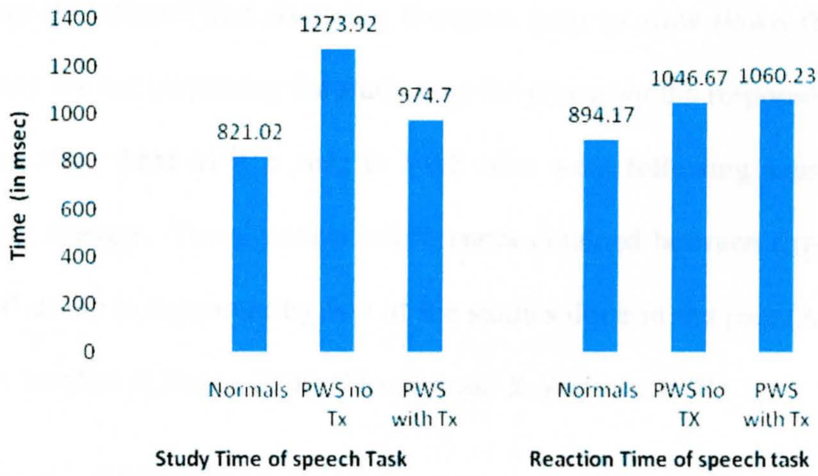
b] Speech Task: Speech study time [ST] and Reaction Time [RT]

Table 3: Mean (in msec) and Standard deviation for speech study time and reaction time across subjects.

Experimental conditions	Groups	N	Mean	Standard deviation	F value	sig
Study Time						
Speech Study Time	Normals	25	821.02	397.60	5.853	.005*
	PWS no Tx	10	1273.92	338.72		
	PWS with Tx	15	974.70	277.88		
Reaction Time						
Speech Reaction Time	Normals	25	894.17	250.97	2.646	0.081
	PWS no TX	10	1046.67	276.46		
	PWS with Tx	15	1060.23	219.70		

"*" = significant difference at 0.05 level of significance for ST

Graph 2: Mean (in msec) of ST and RT for speech task between groups.



MANOVA was used to check the differences across groups statistically for the speech study time and reaction time tasks. As it is evident from Table 2, there is a significant difference at 0.05 level across the subject groups for speech study time task (SST). From the mean values, we can infer that the overall study time for the SST was shortest for normal controls followed by PWS with treatment and finally by PWS without treatment. From table 3, it is also evident that the normal controls took shorter reaction time for programming the individual speech movements compared to the other two experimental groups. Within the experimental groups, PWS with treatment had shorter reaction time compared to PWS without treatment. But, both the experimental groups had significantly longer reaction time compared to normals.

The results suggests that PWS with or without treatment takes longer time than normal controls while preparing the responses in advance before they execute the speech movements. Also, it is evident that the study time is shorter for persons who have undergone treatment than who have not undergone any form of fluency therapy. Though it may be inferred that stuttering therapies help to slow down the overall speech rate, they are not increasing the study time for preparing the responses rather it is reducing the study time as it is seen in PWS who were following some kind of fluency shaping therapy. The significant differences obtained between experimental and the control group is supported by few of the studies done in the past (Aravind & Savithri, 1998; Savithri & Pooja, 2000; Dembowski & Watson; 1991)

Aravind et. al., (1998) found that there was a significant difference between normals and experimental group consisting of PWS in terms of choice reaction time tasks. It was reported that PWS showed longer in choice reaction time in a paradigm task reflecting the INT process as the word length and task complexity was increased. It was also described that PWS showed a deficient motor programming which surfaced when the complexity and speed of the task increases.

From Table 3 and Graph 2 it can be observed that the mean scores are shortest for the normal control group, followed by PWS with no treatment and finally by PWS with treatment in the speech reaction time (SRT). But, the MANOVA results show that the mean scores are not different across the subject groups. Hence it can be understood that the speech reaction time which was elicited using a simple reaction time paradigm is less sensitive to understand the motor programming errors seen in PWS. Alternatively, it could also be argued that individuals with stuttering do not show any errors in speech reaction time reflecting intact SEQ. It other words, whatever planning and organizational difficulties PWS might have while preparing the responses, once initiated, the production of responses was comparable to those who do not stutter. From the above findings it can be understood that PWS do not have any reaction time deficits with respect to speech modality. Hence, it could be postulated that, PWS can be described as having modality independent INT deficit, where they exhibit significant difficulties in the organization of spatio-temporal variables within an individual unit of utterance with intact SEQ.

To understand which of the groups showed significant differences in the speech study time, Duncan's post hoc analysis was carried out.

Table 4: Duncan's Post hoc test for speech study time across subject groups

Groups	N	Subset	
		1	2
Normals	25	821.02	
PWS with Tx	15	974.70	
PWS with no Tx	10		1273.92
Sig		.249	1.000

Duncan's post hoc test reveals that, there were no significant differences between normal controls and PWS who have undergone therapy. But, significant differences were found between normal controls and PWS with no treatment; PWS with treatment and PWS without treatment. Question as to how fluency shaping therapies such as prolongation or airflow therapy influenced study time favorably by reducing the overall reaction time for preparing the responses yet remain to ve verified and further analyzed. It can probably be reasoned out that many of the fluency remediation therapies would provide sufficient time to plan the upcoming utterances by reducing the overall speech rate and this inturn gets reflected in the preparation of responses in advance. A similar notion has been supported by the study done by Savithri and Pooja (2000) wherein a reduced reaction time was observed after therapy in PWS. In contrast to this observation, the study time seems to be longer in PWS who have not undergone treatment.

A modality independent motor programming deficit in PWS seem to gain an upper hand with the above findings. Overall, there was a significant difference between non speech and speech study time. Hence it can be inferred that PWS exhibit modality independent INT deficit irrespective of variables like treatment and severity of the condition.

B] Within group comparison across non speech and speech task

Within group comparison of ST and RT with respect to non speech and speech task is presented in this section

i) Within group comparison of normals for non speech and speech tasks.

Table 5: Mean (in msec), Standard Deviation and paired t test values of normals for non speech and speech tasks

Condition	N	Mean	SD	t	df	Sig. (2-tailed)
Non speech task						
Non speech study time	25	1049.79	331.66	4.085	24	0.000
Non speech reaction time	25	815.90	227.86			
Speech task						
Speech study time	25	821.03	397.60	0.905	24	0.375*
Speech reaction time	25	894.17	250.87			

Graph 3: Mean (in msec) values of normals for non speech and speech tasks

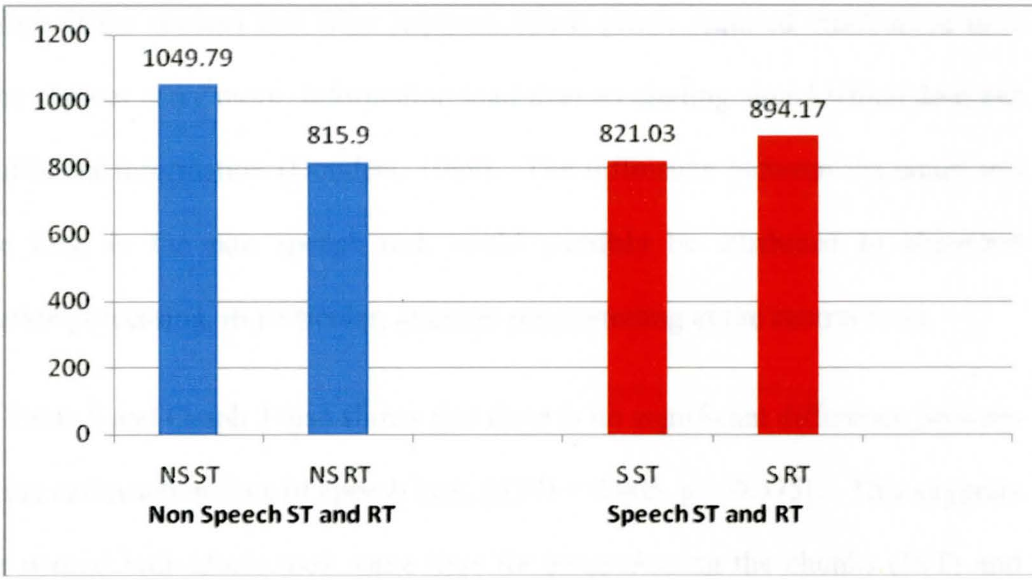


Table 5 and Graph 3 shows that the mean of the non speech study time (NSST) is longer than the non speech reaction time (NSRT) in normals. Paired t test revealed significant difference between the two tasks, [$t(24) = 4.085$, $p < 0.001$]. In a choice reaction time paradigm (CRT) , subjects had to scan between the choices presented visually on the screen and decode the meaning of the choice which took more time in the non speech task than a simple key press after a visual cue which is seen in a simple reaction time paradigm (SRT). Hence it is possible that the normal controls have taken longer time in non speech task for ST as they had to decode the various conditions (1short, 1 long, 4 short and 4 long) presented on the screen than pressing a button soon after an alerting signal given in a SRT. Since we know that study time delineates INT and reaction time the SEQ process of the Klapp's model (1995, 2003), it is been observed that programming of the spatio temporal structure of an individual unit of utterance i.e. INT takes longer time than a mere sequence of the programmed structure i.e. SEQ. It may be understood in the backdrop of additional processing of the choices that were required which inturn required much more time since the choices carry more information load than an alerting signal which does not have sufficient information (Donders, 1969). The difference between the study and reaction time in the non speech task could possibly be attributed to abnormal information processing, in particular, aberrant programming at the central level.

Table 5 and Graph 3 also shows that there is no significant difference between study time and reaction time of speech task, [$t(24) = 0.905$, $p = 0.375$]. This suggests that the normal individuals took same time for programming the chunks (INT) and also in the online retrieval of those chunks.

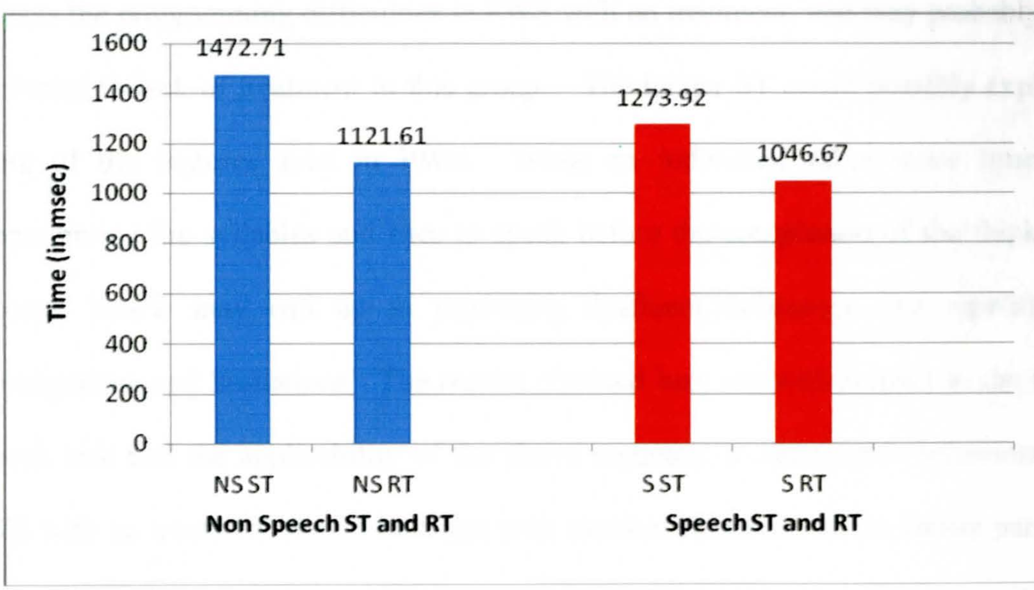
In the speech task, the subjects were given visual cues like 1short, 1long, 4short and 4long and they were asked to utter a non sense syllable /pa/ which varied in duration and sequence length. Here, the experiment provided a scope for creating an artificial association between the visual cue and the responses that were produced verbally. Thus, the subjects were made to artificially associate a visual cue with a verbal response. This association might have created an additional load on processing the visual stimuli and this could have inturn affected the online retrieval of the individual syllables. Hence, there is no significant difference in the study time and the reaction time.

ii) Within group comparison of non speech and speech tasks in PWS with no treatment

Table 6: Mean (in msec),Standard Deviation and paired t test values of PWS with no treatment within non speech and speech tasks.

Condition	N	Mean	Standard deviation	t value	df	Sig. (2-tailed)
Non speech task						
Non Speech Study Time	10	1472.71	324.71	3.181	9	0.011*
Non Speech Reaction Time	10	1121.61	360.06			
Speech task						
Speech Study Time	10	1273.92	338.72	2.635	9	0.027*
Speech Reaction Time	10	1046.67	276.46			

'*' = significant at 0.05 level of significance.



Graph 4: Mean (in msec) values of PWS with no treatment within non speech and speech tasks.

From table 6 and graph 4 it is evident that the ST and RT is different in non speech and speech task and they were significantly different from each other at .05 level of significance in the non speech task for PWS with no treatment, $[t(9) = 3.181, p < 0.05]$. The Study time is longer than the reaction time in non speech and speech task which implies that PWS with no treatment took longer time in pre-programming the individual unit of chunks (INT) and shorter time while retrieving those chunks from short term motor buffer (SEQ). The trend seen here is along expected lines since, ST should be longer compared to RT. However, when compared with the absolute means of normal subjects in table 5 it seems to be longer. Hence it can be logically concluded that PWS with no treatment have longer ST and RT in the non speech task compared to normals.

The longer ST and RT reflecting the INT and SEQ processes respectively reflects the programming difficulties in PWS with no treatment, and may probably be attributed to lack of treatment in this group. The longer ST could possibly explain some of the features seen in PWS. When an individual takes more time in programming the syllables and tries to speak before the completion of the thinking process, he/she may end up in producing dysfluent utterances like repetitions prolongations and hesitations'. The results obtained here are with respect to the non speech task and the applicability of the above argument to the speech behaviors of PWS with no treatment should be taken with caution. However, In the earlier part of this chapter PWS revealed modality independent deficit in ST task, which strengthens the argument of applying the non speech results to the speech characteristics of PWS with no treatment. Duncan's post hoc analysis also revealed no significant difference between normals and PWS with treatment which suggests that treatment variable have a favorable effect on programming the internal spatio-temporal aspects of different syllables.

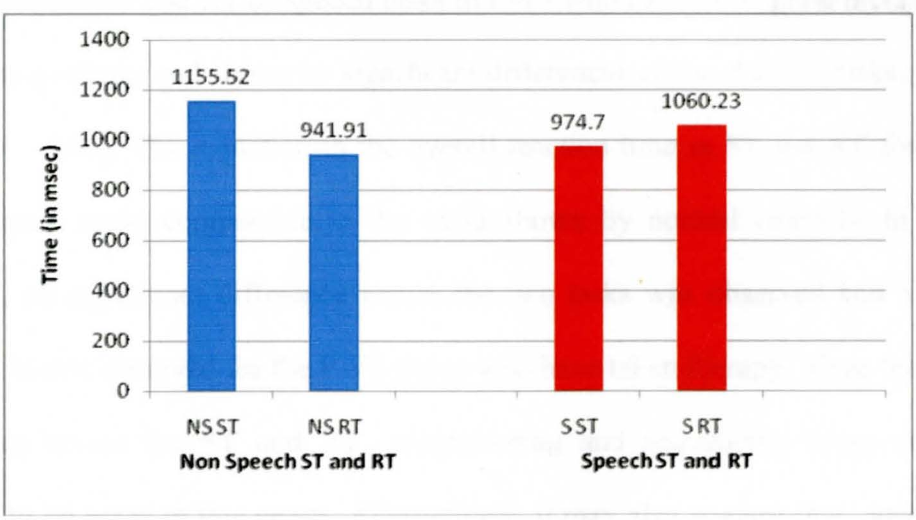
An evident significant difference between the study time and the reaction time in the speech tasks for PWS with no treatment was seen and this was also found tobe significant, $[t(9) = 2.635, p < 0.05]$. It can thus inferred that PWS with no treatment take longer time in programming the spatio temporal parameters of the syllable /pa/ which inturn is reflected as a longer ST. But, the shorter RT shown by this group compared to ST reveals that they have problem in retrieving the programmed sequences. They have a longer INT and shorter SEQ processing time. Normal controls did not show such differences and comparatively their reaction times were much shorter in the speech task.

In normals, the speech motor control system was capable of associating the visual cue presented and the response required rapidly and since speech is a ballistic movement requiring the whole speech motor control system to participate, they did not show any differences between ST and RT. But the scenario is different in PWS where their speech motor control system is not well tuned and hence there is a difference in ST and RT, implicating INT and SEQ respectively.

iii) ***Within group comparison of PWS with treatment in non speech and speech tasks***

Table 7: Mean (in msec),Standard Deviation and paired t test values of PWS with treatment within non speech tasks.

Condition	N	Mean	Standard deviation	t	df	Sig. (2-tailed)
Non speech task						
Non Speech study time	15	1155.52	402.23	1.925	14	0.075
Non Speech reaction time	15	941.91	283.70			
Speech task						
Speech study time	15	974.70	277.88	0.941	14	0.363
Speech reaction time	15	1060.23	219.70			



Graph 5: Mean (in msec) values of PWS with treatment within non speech and speech tasks

From table 7 and graph 5 it can be inferred that the mean scores of ST were longer compared to RT in non speech task in PWS with treatment. This trend is similar to what is observed for normal controls. The result seems to suggest that the treatment variable could have reduced the overall ST and RT in the non speech modality for PWS. However, as revealed from the t test [$t(14) = 1.925$, $p > 0.05$] the mean scores were not significantly different across ST and RT. Another explanation for this trend could be an increased arousal level in PWS due to improved speech fluency that may have resulted in shorter reaction time across both ST and RT thereby compromising the differences between the two. The increased arousal level in the speech tasks may have probably influenced the other modality, that is non speech and hence no significant difference was observed across the task (Hurford & Webster, 1985).

It is also evident that no significant difference was seen between ST and RT exists between ST and RT of speech tasks in PWS who have undergone therapy. The t test also confirms and shows no significant differences across the two tasks, [$t(14) = 0.941$, $p > 0.05$]. The reduction in the overall reaction time in ST and RT for speech task is once again comparable to the trend shown by normal controls. In normal controls, no significant difference across the two tasks was observed and a similar findings is also observed for the PWS group who have taken therapy. Since there is no difference across the ST and RT, programming and sequencing times could be inferred to be equal in this group. Alternatively, it may also suggest that speech task may not be a sensitive measure to understand the programming errors if any seen in PWS due to the fact that it does not reveal significant differences between ST and RT.

C] Within subject comparison for different conditions

The ST and RT, as explained in the method section was elicited in 4 conditions, i.e. 1S, 1L, 4S & 4L. In order to understand the differences if any between ST and RT with respect to these conditions within the group, repeated measure ANOVA was run. The results in this section is presented and discussed with respect to the following subsections:

i) Normal controls

ii) PWS with no treatment

iii) PWS with treatment

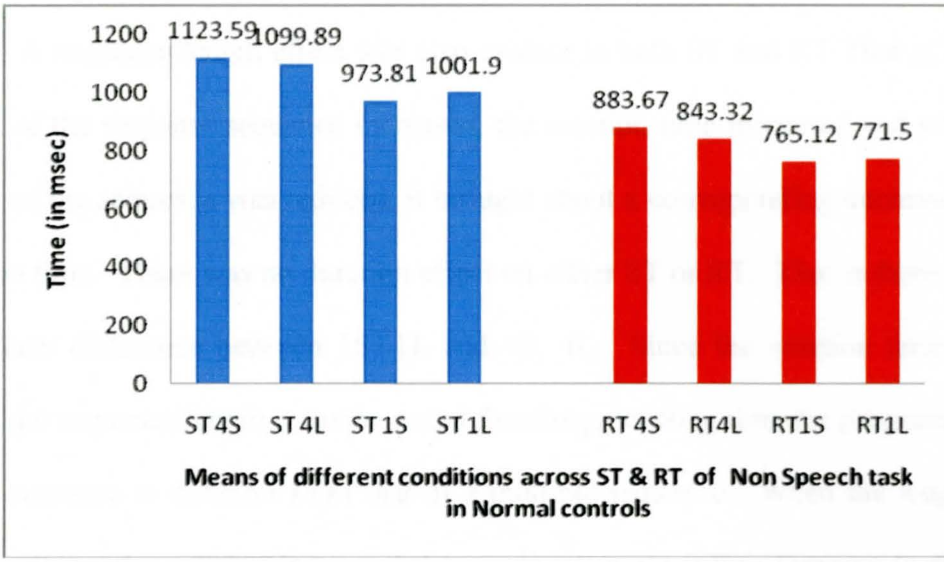
i) Normal controls:

a)Non speech task.

Table 8: Mean (in msec) and standard deviation of different conditions of non speech tasks in Normal controls.

Conditions	Mean	Standard Deviation
NSP ST 4S	1123.59	442.62
NSP ST 4L	1099.89	436.67
NSP ST 1S	973.81	283.92
NSP ST 1L	1001.90	335.38
NSP RT 4S	883.67	280.41
NSP RT 4L	843.32	291.47
NSP RT 1S	765.12	280.27
NSP RT 1L	771.50	295.83

Graph 6: Mean scores (in msec) of ST & RT across different conditions of non speech tasks in Normal controls.



From table 8 and Graph 6 it is evident that the mean reaction time for 4S and 4L conditions was longer than the 1S and 1L in both Study Time and Reaction Time. Repeated measure ANOVA results revealed that all the conditions across the ST and RT were significantly different from one another respectively [$F(3, 72) = 2.868$, $p < 0.05$, $F(3, 72) = 11.882$, $p < 0.05$].

Paired Sample t test was run on the ST task to understand the differences within the conditions. It revealed that only the conditions 4S and 1S [$t (24) = 2.117$, $p < 0.05$)], 4L and 1S [$t(24) = 2.088$, $p < 0.05$)] were significantly different with each other ST, and none of the other pairs were significant.

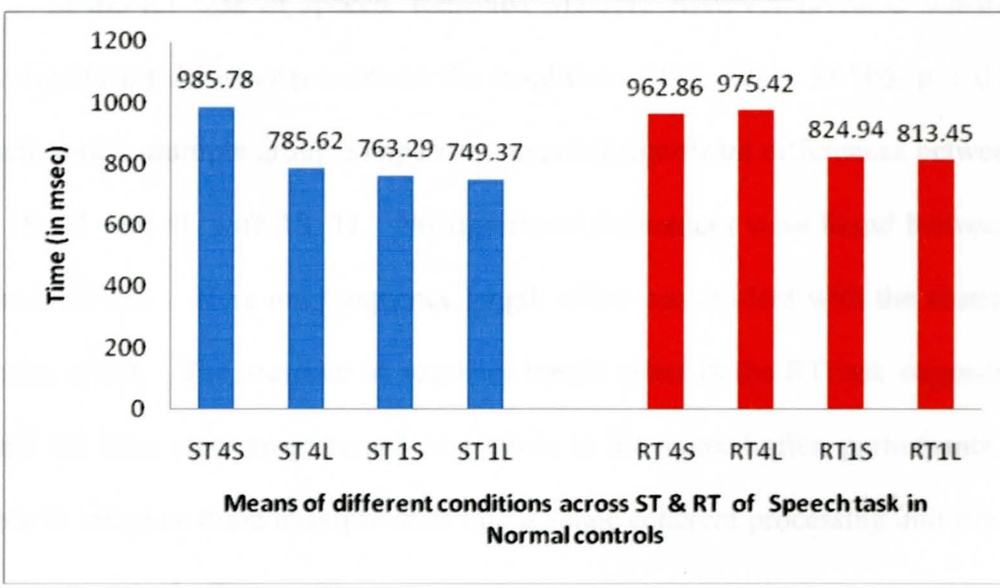
Since the Repeated measure ANOVA revealed significant differences within conditions in the RT task, Boneferroni's multiple group comparison was used to check which conditions were significantly different with respect to each other. It was found that 4S and 4L were significantly different when compared to 1S and 1L. But within 1S, 1L and 4S, 4L there was no significant differences.

A sequence length effect was also evident in both ST and RT That is, as the length of the response sequence increased, the reaction time increased and when the length of the sequence was reduced, it brought about a corresponding decrease in the reaction time. There was no duration effect on either ST or RT. That is there was no significant difference between 1S, 1L and 4S, 4L. Since the reaction time varied across the sequence length it can be stated that the processing time for programming a single response is different from that of a multiple sequence. When the length and complexity of the syllable increased there was a corresponding increase in the time taken to process the stimuli. Hence, programming a short utterance and a longer one varied in normals across non speech tasks.

b) Speech Task

Table 9: Mean (in msec) and standard deviation of ST & RT across different conditions of speech task in normal controls.

Conditions	Mean	Standard Deviation
SP ST 4S	985.78	1071.45
SP ST 4L	785.62	339.42
SP ST 1S	763.29	291.44
SP ST 1L	749.37	286.75
SP RT 4S	962.86	263.29
SP RT 4L	975.42	283.56
SP RT 1S	824.94	235.98
SP RT 1L	813.45	251.83



Graph 7: Mean (in msec) of ST & RT across different conditions of Speech tasks within normal controls

The graph 7 shows no difference between the conditions when the response sequence was varied in ST task i.e. there was an absence of sequence length effect. Also, there is no differences between the responses requiring same sequences i.e. 4S, 4L and 1S, 1L, revealing once again that there is no duration effect on the ST of speech task. Further repeated measure ANOVA showed no significant difference across different conditions in ST task, [$F(3, 72) = 1.155$, $p > 0.05$].

Absence of sequence length effect suggests that all the units, irrespective of the length seemed to be preprogrammed as a single chunk in the ST task and the absence of duration effect suggests that the addition of the syllable duration did not tax the speech motor system

In the RT task of speech, Repeated Measure ANOVA revealed statistically very significant differences between the conditions, [$F(3, 72) = 33.105$, $p < 0.001$]. Boneferroni's multiple group comparison revealed significant differences between 4S and 1S, 1L and 4L with 1S, 1L. No significant differences were found between 4S, 4L and 1S, 1L. Here only sequence length effect was evident with the absence of duration effect. The presence of sequence length effect in the RT task suggests that though the units were programmed as a whole in the motor buffer, participants were unable to integrate these multiple units into a single coherent processing unit from the short term motor buffer.

ii) PWS with no treatment

Table 10: Mean (in msec) of ST & RT and standard deviation across different conditions of non speech task in PWS without treatment

Conditions	Mean	Standard Deviation
NSP ST 4S	1587.73	456.31
NSP ST 4L	1587.05	461.11
NSP ST 1S	1345.70	339.43
NSP ST 1L	1370.36	295.98
NSP RT 4S	1213.72	453.59
NSP RT 4L	1126.03	331.07
NSP RT 1S	1062.14	398.87
NSP RT 1L	1084.57	397.54

Graph 8: Mean (in msec) of ST & RT across different conditions of non speech task in PWS without treatment.

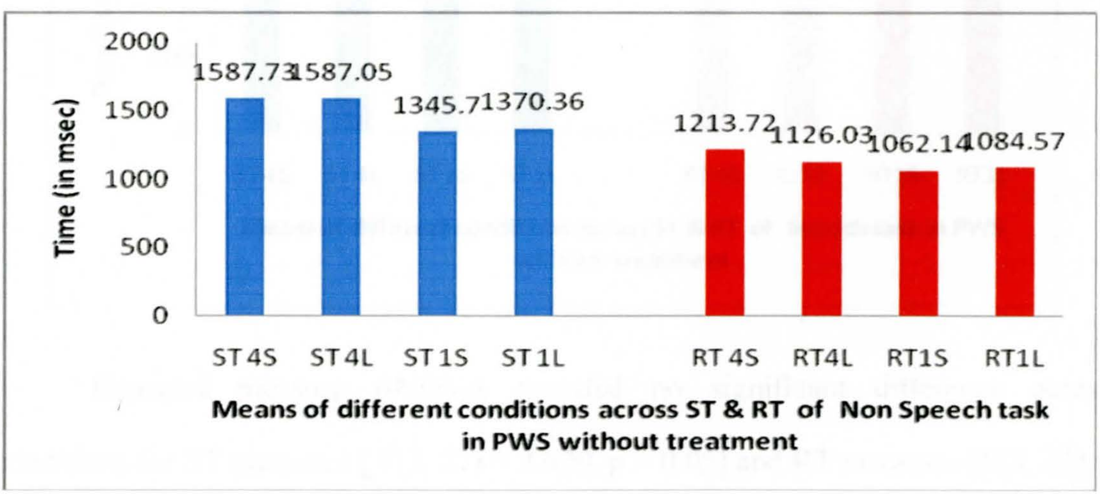
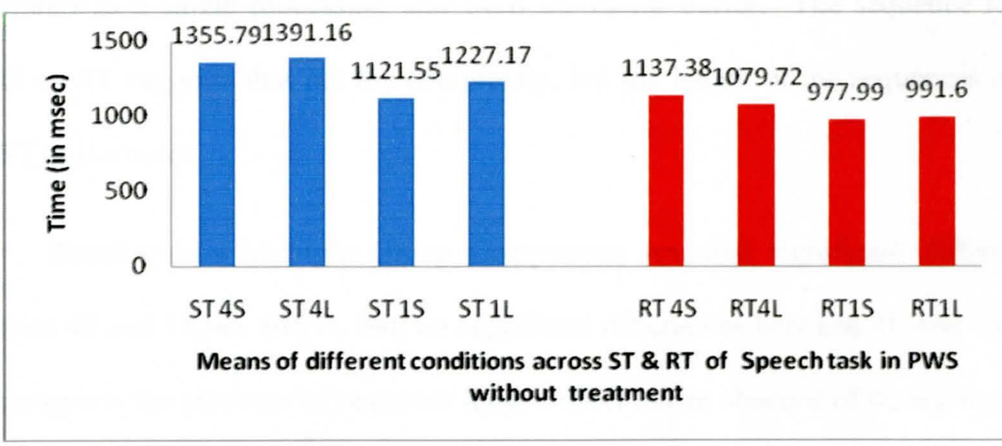


Table 11: Mean (in msec) of ST & RT and standard deviation across different conditions of speech task in PWS without treatment

Conditions	Mean	Standard Deviation
SP ST 4S	1355.79	450.33
SP ST 4L	1391.16	549.24
SP ST 1S	1121.55	248.10
SP ST 1L	1227.17	303.78
SP RT 4S	1137.38	295.43
SP RT 4L	1079.72	287.09
SP RT 1S	977.99	288.57
SP RT 1L	991.60	275.23

Graph 9: Mean (in msec) of ST & RT across different conditions of speech task in PWS without treatment.



Repeated measure ANOVA revealed no significant difference across conditions for ST measures [$F(3, 27) = 2.620$, $p > 0.05$] and RT measures [$F(3, 27) = 1.177$, $p > 0.05$] of non speech task in PWS without treatment there was no significant difference across conditions also in ST measures [$F(3, 27) = 2.300$, $p > 0.05$] of speech task. There was however revealed a significant difference between the conditions in RT measures [$F(3, 27) = 7.422$, $p < 0.01$] of the speech task.

The graph 9 also reveals a longer reaction time for longer sequences in ST and RT of non speech task and ST of speech task. These differences were however not statistically significant. There was also a lack of duration effect in all the tasks. Lack of sequence length effect in both ST of non speech and speech tasks in PWS with no treatment shows no differences in programming a shorter or a longer chunk. This indicates that PWS with no treatment will take same amount of time irrespective of the utterance length and complexity. This suggests that these individuals could have problems not only in programming a longer utterance but also in programming the shorter utterances as well. Also, there was no sequence length effect in the RT of non speech task and this reveals that these participants were unable to integrate the group of chunks as a single processing unit from the motor buffer. The sequence length effect on ST suggests that not the complexity, but the length of the sequences affect the ST of the tasks.

Boneferroni's Multiple Group Comparison revealed significant differences between 4S and 1S, 4S and 1L but, no significant differences between 4L and 1S, 1L. This supports the presence of sequence length effect but an absence of duration effect. Hence it may be concluded that the sequence length will affect both INT and SEQ but not the complexity. The findings also reveals that even without treatment, PWS could probably handle their motor system without any difficulties only with respect to the varying conditions in the RT task of speech only, which is however non substantiable . Hence the favorable effect of treatment on the RT of speech task in PWS without treatment is highly questionable.

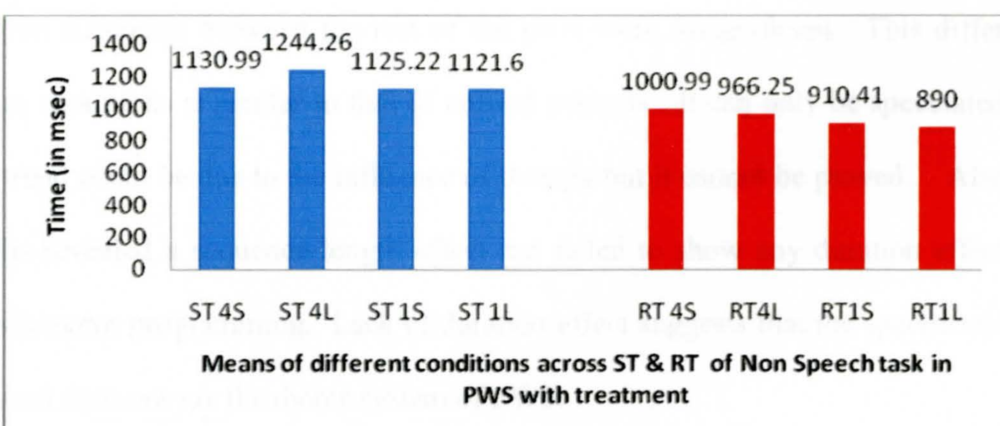
iii) PWS with treatment

a) *Non speech task*

Table 12: Mean (in msec) and standard deviation for ST & RT across different conditions of non speech task in PWS with treatment

Conditions	Mean	Standard Deviation
NSP ST 4S	1130.99	500.12
NSP ST 4L	1244.26	545.48
NSP ST 1S	1125.22	329.61
NSP ST 1L	1121.60	395.24
NSP RT 4S	1000.99	337.51
NSP RT 4L	966.25	316.19
NSP RT 1S	910.41	282.05
NSP RT 1L	890.00	263.30

Graph 10: Mean (in msec) of ST & RT across different conditions of Non speech task in PWS with treatment.



Repeated measure ANOVA revealed no significant differences between conditions in ST of non speech task, [F (42, 3) = 0.956, p > 0.05]. When compared to

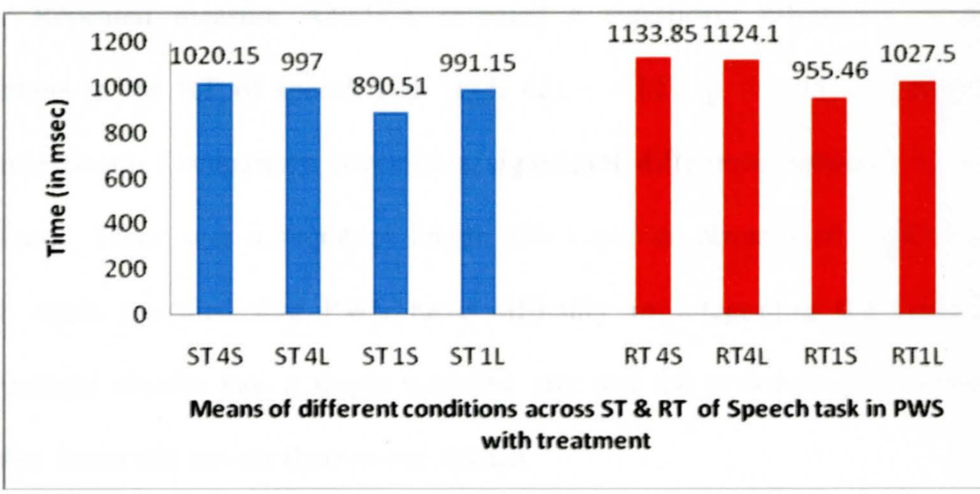
PWS with no treatment (table10 and graph 8) the reaction time of PWS with treatment is much shorter. This could be attributed to the treatment variable but, it is not statistically significant. The reduction in non speech reaction time in this group is difficult to understand in the purview of influence of therapy to improve speech. The question as to whether the effect of treatment is crossing over to the speech modality can be speculated. There was no sequence length or duration effect on the responses indicating that, PWS even after treatment persistently showed some kind of aberrant motor programming because there was no difference shown in the time for programming either short or a longer unit of utterances. Deficit in the ST inturn reflects on the errors in INT sub stage of Klapp's model (1995, 2003). This leads to postulate that reveals that though treatment had a positive effect on motor programming, it could not rectify completely the deficit seen in PWS.

On the other hand PWS with treatment showed significant differences across conditions in the RT of non speech task [$F (42, 3) = 2.855$, $p < 0.05$]. Boneferroni's Multiple Group Comparison revealed that only 4S and 1S were significantly different and the difference between the rest of the pairs were insignificant. This difference across conditions is similar to that of normal controls. It can only be speculated that this trend could be due to the influence of therapy but it cannot be proved. Also, the results revealed a sequence length effect but failed to show any duration effects on speech motor programming. Lack of duration effect suggests that the specification of duration does not tax the motor system of PWS.

b) Speech task

Table 13: Mean (in msec) and standard deviation of ST & RT across different conditions of Speech task in PWS with treatment

Conditions	Mean	Standard Deviation
SP ST 4S	1020.15	387.00
SP ST 4L	997.00	322.01
SP ST 1S	890.51	218.79
SP ST 1L	991.15	282.71
SP RT 4S	1133.85	241.11
SP RT 4L	1124.10	316.48
SP RT 1S	955.46	205.44
SP RT 1L	1027.50	266.43



Graph 11: Mean (in msec) of ST & RT across different conditions of Speech task in PWS with treatment.

Table 13 and graph 11 is represents the means and standard deviation of different conditions. Repeated measure ANOVA across conditions revealed that there is no significant difference between conditions in the ST of the speech task [$F(3, 42) = 2.056$, $p > 0.05$]. There is no statistically significant difference between shorter and longer sequences suggesting that the motor programming of speech was apparent even after PWS had undergone therapy. But the reaction time of PWS with treatment was shorter compared to the PWS with no treatment. This suggests a positive trend towards improvement, but this trend is stillnot comparable with that of normal controls.

The deficit in the INT stage across speech and non speech modality is supportive of the central modality independent deficits. This suggests that PWS with or without treatment will have aberrant programming of the organization of internal spatio temporal structure of an individual unit of utterance.

Repeated measure ANOVA revealed a significant difference across the conditions in the RT of speech task [$F(3, 42) = 4.121$, $p < 0.05$]. Boneferroni's Multiple Group Comparison revealed a significant difference between 4S and 1L condition. There was a sequence length effect and an absence of duration effect which again revealed that PWS have difficulty in integrating the individually programmed chunks into a single cohesive unit and the presence of duration as a complex factor did not tax their motor system.

D] Within condition comparison across groups

To understand the within subject differences across the groups, Multivariate Analysis of Variance i.e. MANOVA was carried out. Since the subject size was less, the MANOVA results were cross verified with Kruskal-Wallis test.

Table 14: MANOVA results for different conditions across groups

Dependent Variable	F (2, 47)	Sig.
nspST4S	3.972	.025*
nspST4L	3.739	.031*
nspST1S	5.279	.009*
nspST1L	4.025	.024*
nspRT4S	3.453	.040*
nspRT4L	3.131	.053*
nspRT1S	3.545	.037*
nspRT1L	3.708	.032*
spST4S	.770	.469
spST4L	8.932	.001*
spST1S	6.650	.003*
spST1L	10.465	.000*
spRT4S	2.676	.079
spRT4L	1.304	.281
spRT1S	2.163	.126
spRT1L	3.720	.032*

"*" = significant results at 0.05 level of significance.

Here 'nspST' = Non speech Study Time

'nspRT' = Non speech Reaction Time

'spST' = Speech Study Time

'spRT' = Speech Reaction Time

Table 14 is shows a significant difference between the conditions considered in the experiment. As is revealed in the table 14, for the Study Time (ST) and Reaction Time (RT) all the four conditions (4S, 4L, 1S, 1L) in the Non speech task were significantly different across the groups. In the ST of Speech task, conditions like 4L, 1S and 1L were significantly different across the groups and in the RT, only 1L was significantly different across the groups.

The findings revealed that Non speech ST and RT showed a significant difference between groups. It was noted in the earlier sections that, reaction times across different conditions in the non speech tasks were shorter in normals followed by PWS with treatment and finally by PWS without treatment and this could have led to the overall significant difference between the groups. Variation in ST and RT of non speech task could have occurred due to the presence of sequence length effect where there was a trend of getting lower reaction time scores for shorter responses and longer reaction time scores for longer sequences and this varied depending on the treatment variable. Though treatment variable brought the reaction time scores of all the conditions nearer to the Normal controls, the scores did not vary with respect to complexity and sequence length and this could have produced an overall significant difference of Non speech ST and RT across the groups.

The ST of Speech task produced significant differences between the groups in conditions like 4L, 1S and 1L. When the results of within group comparison of different conditions were discussed, there were no significant differences between the mean scores in ST within all the groups but, the reaction times were again shorter for normals followed by PWS with treatment and finally by PWS without treatment. These individual differences of reaction times across groups could be the reason for the statistically significant differences between the conditions across groups. In the RT of speech task there was no significant difference across groups found. This could be due to the fact that all hearing adults are highly skilled in sequencing and controlling the syllable duration due to continuous practice in speaking over their lifetime. Also, it has been reported in the motor learning literature that a sequence of units may completely get reorganized as a single unit due to extensive random practice (Klapp, 1995; Sakai, Hikosaka & Nakamura, 2004; Wright et. al., 2004) Though, different stimulus varying in length and complexity was presented, it could have been reorganized as a single chunk, because of which there was no significant difference in various conditions across groups.

MANOVA was followed by Duncan's Post hoc analysis test, which was carried out to know the factors that accounted for the group difference.

Few of the dependent variables of ST (4L, 1S, 1L) , RT (4S, 4L, 1S, 1L) of non speech task and RT (1L) of speech task were significantly different between Normal controls and PWS with no treatment. But, normal controls and PWS with treatment were similar with respect to above variables. Also, PWS with treatment and PWS with no treatment were similar across the above variables. These findings show that normals and PWS with no treatment behaved like two different groups across various conditions taken in the experiment but, PWS with treatment were falling between the normal controls and PWS with no treatment.

a) Few of the dependent variables of ST (4L, 1S) of Speech task and ST (4S) of Non speech task were significantly different between normal controls and PWS with no treatment. But, normals and PWS with treatment were similar in the above variables.

b) Only in one of the variable i.e. spST1L all the groups were significantly different across each other.

From the above findings we can observe a trend where normals and PWS with no treatment were significantly different with each other across most of the dependent variables but, the groups of PWS with treatment and normal controls were similar across many conditions taken in the experiment.

The results of MANOVA were verified with Kruskal-Wallis test. Table 15 represents chi square values of Kruskal Wallis test obtained for various conditions considered in the experiment.

Table 15: Chi-square and its significance of Kruskal- Wallis test within conditions across groups

Conditions	$X^2(2)$	Sig.
nspST4S	7.649	.022*
nspST4L	6.819	.033*
nspST1S	9.222	.010*
nspST1L	7.344	.025*
nspRT4S	3.699	.157
nspRT4L	3.234	.198
nspRT1S	4.817	.090
nspRT1L	4.872	.088
spST4S	9.734	.008*
spST4L	14.889	.001*
spST1S	11.088	.004*
spST1L	15.164	.001*
spRT4S	6.487	.039*
spRT4L	2.066	.356
spRT1S	4.067	.131
spRT1L	6.011	.040*

. "*" = significant at 0.05 level of significance.

The results of Kruskal- Wallis test revealed that all the conditions in the ST of Non Speech task were significantly different across groups but, no significance was seen within all the conditions of RT of non speech task. The present findings were matching with MANOVA results of ST of non speech task. It can be concluded that ST differed significantly across the groups in non speech task. It can also be stated keeping the results in mind that within subject comparison of different conditions reveals that PWS have deficit at the INT stage of motor programming. The findings of MANOVA and Kruskal-Wallis are showing contradictory results with respect to the RT of the non speech task. But going by findings of within subject comparison of different conditions, it can be stated that there was no significant difference between RT of non speech across subject groups. Also, the results should be explained by keeping the findings of Kruskal-Wallis test, since it has more statistical power than MANOVA when the subject size varies significantly. Hence a deficit at the stage of INT leaving SEQ process intact best explains the non speech motor programming errors seen in PWS.

The findings of both MANOVA and Kruskal-Wallis test reveals that the ST of speech task is significantly different across subject groups. But, the results obtained are contradictory, since none of the groups showed any significant differences within different conditions across groups in the earlier section. However, both MANOVA and Kruskal-Wallis revealed significant differences in ST of speech task, the findings can be interpreted that the PWS have deficit at the INT stage of speech motor programming. In the RT of speech task, few of the conditions are found to be significantly different by MANOVA such as 4S, 4L and 1S and Kruskal-Wallis revealed significant difference across 4L and 1S. Hence, these two tasks were found to be significantly different from each other whereas the other two were not. It is however difficult to conclude whether PWS have deficits in the RT of speech task. This variable has to be studied further in greater detail to delineate the presence of programming errors in the speech task.

Mann-Whitney U test was used to understand the difference between the groups across conditions.

Normals Vs PWS with no treatment: Mann-Whitney U test revealed significant differences across all the conditions in the ST and RT of non speech tasks and ST of speech tasks across groups but, no significant difference was obtained in the RT of speech task across three conditions such as 4L, 1L, and 1S. Hence these findings supports modality independent deficit in PWS in INT stage and modality dependent SEQ difficulty in the Non speech task.

Normals Vs PWS with treatment: Mann-Whitney U test revealed no significant differences across all the conditions except for the conditions of 4L of ST, 1L and 4S of RT of Speech Task. No significant difference across most of the conditions between the two groups could be attributed to the treatment variable. The significant differences seen in the above said conditions should be tested further to understand the group differences.

PWS with treatment Vs PWS with no treatment: Mann-Whitney U test revealed no significant differences across the two groups in majority of the conditions but, there were few conditions which were significantly different across the groups which included 4S in ST of Non speech task and 4L, 1S and 1L of ST of speech task. It can be concluded that PWS with and without treatment did not differ on the majority of the variables but, when it comes to the ST of speech task, there was a significant difference in three out of four conditions suggesting an INT deficit in PWS irrespective of the treatment variable.

a) Overall comparison between the groups

Mixed ANOVA was carried out to understand the overall difference across tasks (Non speech Vs Speech), Timing (ST Vs RT), Duration (Long Vs Short) and conditions (4S, 4L, 1S and 1L)

a) Mixed ANOVA results revealed that there was a significant main effect in Tasks i.e. Non speech Vs Speech tasks, $F(1, 47) = 7.965$, $p < 0.007$. The above finding reveals that there was a significant difference between non speech and speech tasks across groups. As a whole the reaction times were longer in the non speech task where an individual was made to manually press the buttons after a visual cue. Though the finger movements and the speech movements are the finest motor movements seen in human beings, the speech movements are unique due to the fact that it has more than two degrees of freedom whereas the finger movements have lesser degrees of freedom. Along with this, the speech movements are ballistic in nature. Ballistic movements occur as a result of rapid contraction of a muscle group followed by a short period of contraction with the involved structure continuing to move because of momentum. This kind of a contraction would produce various movements at a very faster rate. Hence the reaction time varied across the Non speech and Speech tasks.

b) Mixed ANOVA results revealed significant main effect in Timing i.e. (Study Time Vs Reaction Time)across groups, $F(1, 47) = 9.185$, $p < 0.01$. This is due to the fact that the ST is elicited using the Choice Reaction Time Paradigm (CRT) where an individual has to vary his programming depending on the choice presented visually on the screen. Hence, programming the response based on the choices given will take longer time compared to a task where there is no choice provided, as in RT which uses Simple Reaction Time Paradigm (SRT).

c) Mixed ANOVA for within subject variables revealed Significant main effect for different conditions used across groups, $F(3, 141) = 14.44$, $p < 0.001$. Also, it revealed a significant interaction effect between Task Vs Timing, $F(1, 47) = 22.72$, $p < 0.001$. No interaction effect was found across Task Vs Groups, Timing Vs Groups, Condition Vs groups, Task Vs Conditions, Task Vs Timing, Task Vs Timing Vs Groups, Task Vs Conditions Vs groups, Timing Vs Conditions Vs Groups, Task Vs Timing Vs Conditions Vs Groups, Tasks Vs Timing Vs Conditions Vs Groups.

d) Mixed ANOVA revealed that as a whole across different tasks and conditions, all the groups were significantly different with each other, $F(2, 42) = 6.887$, $p < 0.005$. Duncan's Post hoc analysis revealed no significant difference between Normal controls and PWS with treatment but significant difference was found between Normal controls and PWS with no treatment. It can be concluded that the treatment variable has produced an overall shorter reaction times across tasks; hence there was no significant difference between Normal controls and PWS with treatment. But lack of treatment variable differentiated PWS with no treatment group with the other two groups indicating the importance of treatment variable in speech motor programming.

e) Boneferrroni's multiple comparison of different conditions revealed that the sequences (4s and 4L) were significantly different from (1S and 1L) across tasks. But there was no significant difference between 4S and 4L, 1S and 1L conditions across groups. Also, there was no significant difference in terms of duration i.e. long Vs short across tasks and groups.

***E] Within group comparison of various conditions*:**

Paired t test for the 3 groups was administered to understand the difference across conditions within a particular group.

i)Paired t-test for Normal controls

Table 16: The t-test of Normal controls across different conditions

Pairs	Conditions	t	Sig.
Pair 1	NSPST4S-NSPRT4S	2.783	.010*
Pair 2	NSPST4L-NSPRT4L	3.468	.002*
Pair 3	NSPST1S-NSPRT1S	3.969	.001*
Pair 4	NSPST1L-NSPRT1L	3.503	.002*
Pair 5	SPST4S - SPRT4S	.102	.920
Pair 6	SPST4L - SPRT4L	-2.749	.011*
Pair 7	SPST1S - SPRT1S	-1.141	.265
Pair 8	SPST1L - SPRT1L	-1.139	.266
Pair 9	NSPST4S - SPST4S	.719	.479
Pair 10	NSPST4L - SPST4L	4.465	.000*
Pair 11	NSPST1S - SPST1S	4.381	.000*
Pair 12	NSPST1L - SPST1L	5.044	.000*
Pair 13	NSPRT4S -SPRT4S	-2.015	.055*
Pair 14	NSPRT4L- SPRT4L	-2.842	.009*
Pair 15	NSPRT1S -SPRT1S	-1.666	.109
Pair 16	NSPRT1L -SPRT1L	-1.208	.239

"*" = at 0.05 level of sequence.

From the table 16 it is clear that there was a significant difference between non speech ST and RT at 0.05 level of significance. The difference could be attributed to the nature of the task through which ST and RT is elicited. Study time was elicited using a choice reaction time paradigm where the subjects were made to scan between the choices and were allowed to press response keys only when they thought they were ready to execute the response. This scanning of choices would have created an increased ST in the Non speech task. But, in the simple reaction time paradigm, subjects were familiar with the responses which they were supposed to produce and the appearance of a particular visual cue "Go!" prompted the participants to execute the response. Here, the task demand is less compared to the choice reaction time paradigm.

There was no significant difference between Speech Study Time and Reaction Time. This could be attributed to the virtual association made between visual stimuli and the responses. Here, the subjects were made to produce a non sense syllable /pa/ by varying its length and duration in response to stimuli of a visual word and hence this artificial association could have masked the actual choice and simple reaction time differences across the speech task.

The findings also revealed a significant difference between the non speech and speech study time tasks. This finding could be attributed to the difference in the precise control of articulators to that of the not so precise finger movements. One more factor which could be attributed is the familiarity of the task i.e. speech movements are familiar to a naïve person than the key press responses which would have taken some time to get habituated. There was no significant difference between non Speech and speech reaction time in two of the conditions 1S and 1L. But, there was a significant difference in 4S and 4L conditions. The reason behind the occurrence of such a finding is still unclear and requires further investigation.

ii). *Paired t-test for PWS with no treatment*

Table 17: The t-test of PWS with no treatment across different conditions

Pairs	**Conditions**	**t**	**Sig.**
Pair 1	NSPST4S - NSPRT4S	3.213	.011*
Pair 2	NSPST4L - NSPRT4L	3.309	.009*
Pair 3	NSPST1S - NSPRT1S	1.913	.088
Pair 4	NSPST1L - NSPRT1L	1.890	.091
Pair 5	SPST4S - SPRT4S	1.980	.079
Pair 6	SPST4L - SPRT4L	1.862	.095
Pair 7	SPST1S - SPRT1S	1.699	.124
Pair 8	SPST1L - SPRT1L	2.244	.052
Pair 9	NSPST4S - SPST4S	2.138	.061
Pair 10	NSPST4L - SPST4L	1.175	.270
Pair 11	NSPST1S - SPST1S	2.055	.070
Pair 12	NSPST1L - SPST1L	1.128	.289
Pair 13	NSPRT4S - SPRT4S	.754	.470
Pair 14	NSPRT4L - SPRT4L	.634	.542
Pair 15	NSPRT1S - SPRT1S	.936	.374
Pair 16	NSPRT1L - SPRT1L	1.066	.314

"*" = at 0.05 level of sequence.

Results revealed that only the first two pairs of Non speech Study Time task was significantly different with each other and rest of the other pairs were not statistically significant. There was no significant difference between Speech Study and Reaction Time within PWS with no treatment. Similarly, there was no significant difference between non speech ST and speech ST. Also, there were no significant differences in non speech reaction Vs speech reaction time. This reveals that PWS without treatment had significant programming errors owing to the lack of difference between various conditions.

iii). Paired t-test for PWS with treatment.

Table 18: The t-test of PWS with no treatment across different conditions

Pairs	Conditions	t	Sig.
Pair 1	NSPST4S - NSPRT4S	1.021	.324*
Pair 2	NSPST4L - NSPRT4L	2.272	.039*
Pair 3	NSPST1S - NSPRT1S	1.930	.074
Pair 4	NSPST1L - NSPRT1L	1.945	.072
Pair 5	SPST4S - SPRT4S	-.931	.368
Pair 6	SPST4L - SPRT4L	-1.087	.295
Pair 7	SPST1S - SPRT1S	-.824	.424
Pair 8	SPST1L - SPRT1L	-.388	.704
Pair 9	NSPST4S - SPST4S	1.760	.100
Pair 10	NSPST4L - SPST4L	3.279	.005*
Pair 11	NSPST1S - SPST1S	3.207	.006*
Pair 12	NSPST1L - SPST1L	1.276	.223
Pair 13	NSPRT4S - SPRT4S	-1.827	.089
Pair 14	NSPRT4L - SPRT4L	-1.611	.129
Pair 15	NSPRT1S - SPRT1S	-.731	.477
Pair 16	NSPRT1L - SPRT1L	-1.981	.068

"*" = at 0.05 level of sequence.

It could be observed from the above table 18 that there were only four conditions which were significantly different between each other and rest of them did not show any significant differences. It can be stated that the treatment variable can vary the programming time between non speech ST and RT time tasks across 4L and 4S. It also consistently varies ST across Non speech and Speech tasks. Though the treatment variable has a significant effect on few of the conditions, its influence is minimum across most of the conditions and this could be attributed to the motivation of the client to follow the technique, severity of the problem and the amount of therapy received.

Summary:

To summarize, the analysis of the results indicates a significant difference between normal controls and PWS in the motor programming stages as outlined by Klapp (1995, 2003) in both non speech and speech tasks irrespective of the severity and treatment effect in PWS.

Comparison across groups for non speech and speech tasks revealed that PWS with treatment and without treatment were significantly different from the normal controls in the Study Time (ST) of both non speech and speech task. This suggests a modality independent deficit in the ST which inturn posits a deficit in the INT process. There was no significant difference in the RT in the non speech task, revealing an intact SEQ and aberrant INT process in the non speech task. But, the findings in terms of Speech Reaction Time did not show any consistent trend across the groups hence it needs to be explored further.

Within group comparison revealed significant differences between normals, PWS with no treatment and PWS with treatment in the non speech task. Though the trends were similar in ST and RT of normals and PWS with no treatment group, PWS had longer overall reaction times across ST and RT. The reaction times were shorter for ST and RT of PWS with treatment compared to PWS without treatment but, no significant difference was found between ST and RT which again points to an aberrant motor programming deficit in these groups for the non speech task.

For the speech tasks too, a significant difference between normal controls and PWS with no treatment group was seen but there was some similarity between normal controls and the PWS with treatment group. Although more evidence needs to be established, at this juncture it may only be postulated that this could be due to the effect of treatment variable. Although there was a similar trend the absolute reaction times were significantly longer in PWS group again suggesting a speech motor programming deficit.

Within condition comparisons also revealed significant differences between normal controls and other two experimental groups across non speech and speech tasks. Programming of shorter and longer sequences were significantly different in normals and consistently showed sequence length effect in ST of both non speech and speech task and RT of only non speech task. But both the experimental groups did not show any such effects which, suggests that the programming time did not vary with respect to length of the utterances which seems to be abnormal. The RT did not show any consistent trend in the speech task and there is need for further controlled studies to elaborate the findings.

The differences obtained between non speech and speech tasks could be attributed to the practice effects also. Literature on motor learning shows that extensive random practice can make a sequence of units completely reorganized as a single unit. Thus, the difference obtained could also be due to the practice effects and it is been found that all normal individual are highly skilled in sequencing and controlling the syllable duration in speaking tasks. In contrast, sequencing finger movement is a less familiar task which is less practiced in a typical adult (Klapp, 1995; Sakai, Hikosaka, & Nakamura, 2004; Wright et. al., 2004)

In conclusion though treatment showed favorable effect on the speech motor programming in this experiment which used a Self Select Reaction Time paradigm, all the effects could not be attributed to treatment. Some of the similarities seen between normal controls and PWS with treatment group could be attributed to the motivation factors, arousal, practice effects along with some processing effects which could be taking place in the central mechanism which cannot be addressed with the design used in this study.

SUMMARY AND CONCLUSIONS

The aim of the present study is to delineate the speech motor programming difficulties seen of adults with stuttering. A two stage model proposed by Klapp (1995, 2003) was used to investigate the deficits of speech motor programming in persons with stuttering (PWS). The model proposes two distinctive stages of speech motor programming i.e. INT and SEQ. The first stage INT refers to the organization of internal spatio temporal structure of an individual unit of movement and this would be fed to a short term memory store. The second stage SEQ sequences units into their correct serial order after initiation. It was hypothesized that the programming errors in PWS could be localized to either any one of the two processes and exploration of this would help in understanding more precisely the deficits in the speech motor programming of PWS.

To investigate the deficits in the Speech motor programming, a recently developed reaction time paradigm, "Self Select Reaction Time Paradigm" was used (Immink & Wright, 2001; Wright, Black, Immink, Brueckner & Magnuson, 2004) in the study, where both the INT and SEQ are measured through the index of study time (ST) and reaction time (RT). Klapp (1995, 2003) validated the INT/SEQ model using Choice and simple RT paradigms. In a simple RT paradigm, the response to be produced on a given trial is cued before the imperative signal that prompts response production. This allows pre-programming and reflects the SEQ process and this was measured as Reaction Time (RT). In a choice RT paradigm, the imperative signal specifies the response to be produced, and thus preprogramming is not possible thereby reflecting the INT process and this was measured as Study Time (ST) across tasks. This study proposed to understand the speech and non speech motor programming deficits of PWS using the Self Select RT Paradigm (Wright 2001; Wright et. al., 2004). The objectives of the study were to understand the differences if any between normal controls, PWS with treatment and PWS without treatment with respect to:

g) Motor programming for non speech and speech tasks, and thus its relation to INT or SEQ processes of programming.
h) The modality independent or modality dependent factors with respect to INT or SEQ processes and
i) The effect of treatment in PWS with respect to INT or SEQ processes.

The study included two groups of participants, one was the Normal control group and the other was the Experimental group. The experimental group was further divided into a) Persons with stuttering without treatment b) Persons with stuttering with treatment. There were 25 Normal controls of which 11 were males and 15 were females, 15 PWS were males who had undergone treatment and 10 were PWS without any treatment among which there were nine males and one female. All the participants were in the age range of 16-30 (Mean age = 22.8). Presence of auditory, visual, neurological and motoric deficits was ruled out using suitable screening procedures. Only those individuals with mild to moderate degree of stuttering severity were included in the experimental group Those individuals who had seizures, open head injuries and motoric deficits were excluded. .

The Self Select RT Paradigm (Wright, 2001; Wright et. al., 2004) was developed by the investigator using DMDX software (Kenneth and Jonathan, 2003) and loaded on to a personal computer to run the study. A pilot study was conducted before the actual experiment to investigate the sensitivity and validity of the paradigm developed. Five participants who were not part of the actual experiment, in the age range of 20-26 years were included and both speech and non speech motor programming trials were run. The findings revealed that participants took longer reaction time for the INT task compared to the SEQ task in both speech and non speech task. Also, there were more errors in the first and last blocks and hence it was decided to remove these blocks from the experimental study.

The experimental study included both Speech and Non speech tasks and before conducting the experiment the suitable instructions were provided for non speech and speech tasks separately. Initially, subjects were familiarized with the different key press responses which included a "Short press" and a "Long Press". Each subject was provided with an auditory model regarding "short" and "long" press responses by providing a short and a long tone of 150 ms and 450 ms. Only when the subjects were familiar with the different types of responses that they had to make, the experiment was conducted. Accordingly, four different key press responses to elicit four targets namely; 1S (Single short press: 150 ms), 1L (Single long press: 450 ms), 4S (SLLS sequence: 150-450-450-150 ms), 4L (LSSL sequence: 450-150-150-450 ms) were used. The instructions for the speech task remained the same as non speech task but instead of a key press subjects were asked to say a non sense phoneme /pa/ by varying the duration and length.

There were two experiments

c) Experiment 1: RT paradigm for non speech tasks

d) Experiment 2: RT paradigm for speech tasks.

Same instructions outlined earlier were provided and the mean scores of Study Time and Reaction Time for speech and non speech tasks of the participants were calculated and compared within the group and across the groups and also across four different conditions.

Summary of the results:

There was a significant difference between normal controls and PWS in the motor programming stages outlined by Klapp (1995, 2003) in both non speech and speech tasks irrespective of the treatment variable in effect.

Across the group comparison of non speech and speech tasks revealed that PWS with treatment and without treatment were significantly different from the normal controls in the Study Time (ST) of both non speech and Speech task. This suggests a modality independent deficit in ST which in turn points to a deficit in the INT process. There was no significant difference in the RT in the non speech task revealing an intact SEQ and aberrant INT process in the non speech task. But, the findings of the study in terms of Speech Reaction Time did not show any consistent trend across the groups hence it should be explored further.

Within group comparison revealed significant differences between normals, PWS with no treatment group and PWS with treatment group in non speech tasks. Though the trends were similar in ST and RT of normals and PWS with no treatment group, PWS had longer overall reaction times across ST and RT. The reaction times were shorter for ST and RT of PWS with treatment compared to PWS without treatment but, no significant difference was found between ST and RT which again points towards the aberrant motor programming in non speech task.

With respect to the speech task, normal group were significantly different from PWS with no treatment group but showed some similarity with the PWS with treatment group, the effect of which could probably be attributed to treatment variable. But, though there was a similar trend the absolute reaction times were significantly longer in PWS group again suggesting a speech motor programming deficit.

Within condition comparison also revealed significant differences between normals and other two experimental groups across non speech and speech tasks. Programming of shorter and longer sequences were significantly different in normals and consistently showed sequence length effect in ST of both non speech and speech task and RT of only non speech task. But both the experimental group did not show any such effects, which suggests that the programming time did not vary with respect to length of the utterances which seems to be abnormal. The RT did not show any consistent trend in the speech task suggesting the need to explore this further through more stringent paradigms in future experiments.

The possibilities of the influence of practice effects also needs to be explored in future as literature on motor learning theories shows that extensive random practice can make a sequence of units be reorganized as a single unit. Thus, the effect of needs to be controlled in future studies as it is known that normal individuals are highly skilled in sequencing and controlling the syllable duration in speaking tasks. In contrast, sequencing finger movement is a less familiar task which is less practiced in a typical adult (Klapp, 1995; Sakai, Hikosaka, & Nakamura, 2004; Wright et. al., 2004)

Conclusion:

In conclusion, though treatment showed favorable effect on the speech motor programming as inferred through the Self Study Reaction Time paradigm used in this study, all the effects could not be attributed to treatment. Some of the similarities seen between Normals and PWS with treatment group could be attributed to the motivation factors, arousal, practice effects along with some uncontrolled processing at the central level which cannot be addressed with the design used in this study.

Future Directions:

a) The effect of treatment variable on the non speech motor programming should be studied further to understand the extent of similarity between non speech and speech motor programming.

b) Additional factors other than therapy have to be explored for the improvement seen in the speech motor programming errors in PWS.

c) It has to be checked whether subgroups of PWS can be drawn from the reaction time paradigm used in the study in terms of non speech and speech motor programming deficits.

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